AD NUMBER
AD597033
CLASSIFICATION CHANGES

TO:	unclassified
FROM:	restricted

LIMITATION CHANGES

TO:

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AUTHORITY

DSTL ltr dtd 15 Feb 2007; DSTL ltr dtd 15 Feb 2007

JOURNAL

OF THE

ROYAL NAVAL

SCIENTIFIC SERVICE

AD-597033

Journal of the

ROYAL NAVAL

Decl OADR

SCIENTIFIC SERVICE

Volume 29

Number 1

January 1974

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RESTRICTED

100,157

OPEN CIRCUIT ELECTRODE POTENTIALS OF METALS IN SEA WATER

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Abstract

The measurement of open circuit electrode potentials of 50-No. metals in static and moving sea water is described. The measurements are intended to supplement existing galvanic series for alloys currently used in Naval Service. Factors affecting results are discussed with special reference to time of exposure. Results indicate that longer times are required for metals to reach steady potentials than indicated by previous work, especially in respect to moving sea water. Potentials for high duty materials were found to increase at 10ft./sec., while low duty materials showed decreased potentials. The possibility of measuring impingement resistance by use of electrode potentials is proposed.

Introduction

This article covers the measurement of open circuit electrode potentials (or corrosion potentials) of 50 No. metals in sea water under (a) " static " conditions and (b) at a water speed of 10ft./sec.

The results of such measurements, arranged in order of magnitude, form a " galvanic series " and are widely used for predicting the direction of current flow, when dissimilar metals are coupled together in a particular electrolyte. The most commonly used table, published in 1951[1], lists a comprehensive range of metals in a galvanic series for sea water at a velocity of 13ft./sec., and is frequently quoted without regard for its relevance, when a static series is actually implied. Some materials listed in this table, especially the copper alloys, have now been superseded, and an extension of the table to include more recently available materials is considered necessary.

The present series of measurements was therefore made with the object of supplementing published data especially for naval use, as some materials measured are used exclusively by the R.A.N. The fact that a material was measured does not imply that it is considered suitable for sea water use, as some were included purely for interest or comparison purposes. It should also be noted that although electrode potential measurements may indicate that one material has a higher potential than another, it does not necessarily mean that a significant corrosion current will result if the two are coupled together in sea water. Other factors, such as the area relationship and degree of polarisation must be taken into account.

Factors affecting electrode potentials

When a metal is immersed in an electrolyte it develops an electrode potential across the metal/solution interface. This potential arises due to the tendency of the metal to enter the solution as metal ions in order to achieve equilibrium and is present whether or not metal dissolution (corrosion) takes place. However, when corrosion commences, the potential changes and the new potential results from many anodic (oxidation) and cathodic (reduction) reactions on the surface of the metal. These reactions are dependent on the environment and any change in this will cause a corresponding shift in the electrode or corrosion potential.

Mears and Brown[2] listed twelve factors which they suggested " may influence the solution potential of a metal in a given electrolyte ". These factors were composition of the metal, orientation of grains, surface roughness, local scratches, cut edges, shape, film formation, concentration of the metal ions in the electrolyte, aeration, temperature, illumination and movement of the electrolyte. Many of these effects were confirmed during the current series of tests but others, such as surface roughness, scratches and cut edges, were found to be of short duration and to have no detectable influence after several months. Apart from the environmental factors, time had the most significant effect on potentials and the period required for steady readings varied with the metals. When all factors are considered it is obvious that absolute results are virtually impossible and for practical purposes, are unwarranted.

Method

(a) *Static Potentials*

The samples used were $\frac{1}{2}$in. dia discs embedded in $1 \cdot 0$in. dia epoxy resin metallurgical mounts, so that the front face only was exposed (see photograph). This exposed face was finished with 600 grit emery paper and finally glass scraped before immersion to provide a freshly prepared surface and to remove any contamination from the polishing grit. An insulated pigtail lead was attached to the backface of each sample and the joint sealed in by the epoxy mount.

The number of samples of each material tested was limited to three and although this is small from a statistical point of view, the composition of each material was representa-

tive of the specification quoted and potential deviations were relatively small. The condition of each material was similar to that normally encountered in service, *i.e.*, as cast or wrought with the specified heat treatment.
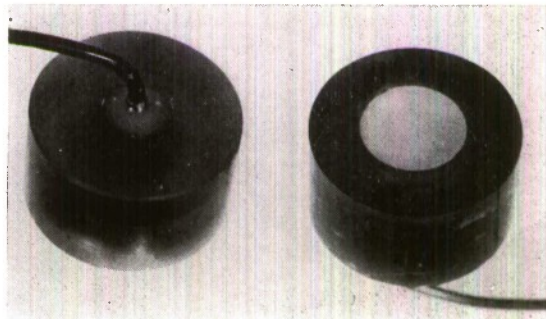
Samples were immersed in one litre beakers and the sea water, which was drawn from Sydney Harbour, was changed every second day. These conditions were not strictly static, but potential measurements before and after water changes showed that once the " steady state " was reached, potentials recovered to the pre-change value within one hour. Natural water movements due to convection currents and dispersion of corrosion products were considered to be acceptable for a static environment.

Potentials were measured at or corrected to a temperature of 25°C against a saturated calomel electrode by means of a digital voltmeter with an input impedance of 25,000 megohms. Readings were taken weekly for six months by which time reasonably steady potentials were obtained for most metals.

(b) *Potentials at 10ft./sec.*

The metal samples were similar in size to those used for static measurements, but were set with epoxy cement into a P.V.C. pipe so that the exposed surfaces were level with the bore. A saturated calomel electrode was mounted so that the tip could be brought close to the material under test and pigtail leads from each sample were terminated at a junction box.

Sea water was pumped through on a " once through " basis at an average speed of 10ft./ sec. which was controlled within $5 \cdot 0\%$ by a flow controller. The actual water speed across each sample was not measured, but it was assumed that boundary conditions of the test set-up would approximate those in actual service with the same water speed.

TABLE OF OPEN CIRCUIT ELECTRODE POTENTIALS IN SEA WATER v S.C.E. 25°C

NO.	MATERIAL	MAT SPEC.	POTENTIAL STATIC VOLTS	TIME TO STEADY POTENTIAL WEEKS	POTENTIAL 10 FT/SEC VOLTS	TIME TO STEADY POTENTIAL WEEKS	LA QUE 13 FT/SEC (REF.1) VOLTS	AD. GUIDE 106 (REF.4) VOLTS	REMARKS
1	Zinc Anode R.A.N. Type	DTR 192/68	-1.04	1	-1.10	10	-	-	
2	Aluminium Wrought	BS. 1470 NE5	-0.78	7	-0.71	13		-0.75	
3	Aluminium 99%	-	-0.76	5	-	-	-	-0.75	-
4	Aluminium Cast	BS. 1490 LM6	-0.75	2	-	-	-	-0.75	-
5	Mild Steel	BS. 970 EN4	-0.74	2	-0.60	4	-0.61	-	See Fig 6
6	Cadmium Commercial	-	-0.70	2	-	-	-	-	-
7	Grey Cast Iron	BS. 1452 GR. 14	-0.68	4	-	-	-0.61	-	-
8	Ni-Resist Low Copper	BS. 3468 Aust. 102	-0.48	3	-	-	-	-	-
9	Ni-Resist High Copper	BS. 3468 Aust. 101	-0.43	5	-	-	-	-0.54	-
10	50/50 Solder Commercial	-	-0.42	1	-	-	-	-	-
11	Tin Commercial	-	-0.35	10	-0.35	33	-	-	-
12	Babbit	BS. 3332/2	-0.33	30	-	-	-	-	-
13	Lead Commercial	--	-0.32	6	>-0.10	40	-	-	Deviations ± 0.08 V
14	"Superston 40"	--	-0.30	9	-0.30	7	-	-0.23	See Fig 3
15	18/2 Stainless Steel	BS. 970 EN57	-0.30	-	-0.13	-	-	-0.14	Variable Potential
16	60/40 Solder	--	-0.29	>40	-0.31	22	-	-	-
17	70/30 Brass	BS. 2871 CZ. 106	-0.26	5	-	-	-	-0.22	-
18	Aluminium Brass	BS. 2871 CZ. 110	-0.23	2	-0.14	10	-	-0.24	
19	95/5 Copper Nickel Iron	BS. 2871 CN. 101	-0.22	4	-0.21	8	-	-0.21	-
20	Alum Bronze AD.Spec.1076	BS. 2032	-0.22	2	-0.09	10	-	-0.22	
21	Alum. Bronze DGS. 8452	BS. 2033	-0.22	3	-0.09	10	-	-0.19	See Fig 1
22	Alum. Silicon Bronze	--	-0.21	1	-0.10	35	-	-	
23	Brass (85/15)	--	-0.21	2	-0.29	1	-0.36	-	-
24	90/10 Copper Nickel Iron	BS. 2871 CN. 102	-0.20	2	-0.19	4	-0.28	-0.20	--
25	Naval Brass	BS. 251	-0.19	3	-0.29	1	-0.40	-0.24	See Fig 5
26	Silver Phos. Copper	BS. 1845 CP. 2B	-0.18	5	-	-	-	-	-

TABLE OF OPEN CIRCUIT ELECTRODE POTENTIALS IN SEA WATER v S.C.E. 25°C

NO.	MATERIAL	MAT SPEC.	POTENTIAL STATIC VOLTS	TIME TO STEADY POTENTIAL WEEKS	POTENTIAL 10 FT/SEC VOLTS	TIME TO STEADY POTENTIAL WEEKS	LA QUE 13 FT/SEC (REF.1) VOLTS	AD. GUIDE 106 (REF.4) VOLTS	REMARKS
27	Nickel Silver 20%	BS. 2870 NS. 108	-0.17	2	-	-	-	-0.18	-
28	Copper	BS. 1172	-0.13	3	-0.25	2	-0.36	-0.21	See Fig 4
29	Phos. Bronze	BS. 369	-0.13	1	-0.12	25	-	-0.20	-
30	Silicon Bronze	BS. 2871 CS. 101	-0.12	11	-0.24	10	-	-0.20	-
31	Be Copper Heat Treatable	-	-0.12	2	-0.22	23	-	-0.21	-
32	Gunmetal	BS. 1400 LG2-C	-0.12	10	-	-	-	-0.20	-
33	Gunmetal	BS. 1400 LG3-C	-0.12	7	-	-	-	-0.19	-
34	Gunmetal	BS. 1400 LG4-C	-0.12	6	-	-	-	-0.20	-
35	Gunmetal	BS. 1400 G1-C	-0.12	4	-0.10	· 21	-	-0.20	-
36	Gunmetal LG4 + 2° Ni	BS. 1400	-0.12	4	-0.10	30	-	-	See Fig 2
37	Brazing Metal	Ad.Spec.1112	-0.11	6	-0.23	30	-	-0.22	-
38	Welbronze 3	RAN Spec. DMS 112	-0.11	4	-0.07	25	-	-	-
39	Nickel Bronze	DGS 6510	-0.11	5	-	-	-	-	-
40	70/30 Copper Nickel	BS. 2871 CN. 107	-0.10	5	-0.07	20	-0.25	-0.18	-
41	Silver Solder	BS. 1845 AG. 1	-0.10	10	-0.05	30	-	-	-
42	Crown Metal	--	-0.10	5	-0.01	35	-	-	-
43	18/8 Stainless Steel (304)	BS. 970 EN. 58	-0.05	-	+0.05	-	-0.08	-0.08	Variable Potentials
44	Titanium Commercial	I.C.I. 130	-0.04	-	+0.04	-	-0.15	-0.05	"
45	Monel	BS. 3076 NA. 13	-0.02	5	+0.02	30	-0.08	-0.12	-
46	Silver-Pure	-	-0.01	2	--	--	-0.13	--	--
ZERO = Ref. Potential (Saturated Calomel Electrode)									
47	18/8 Mo Stainless Steel (316)	BS. 970 EN. 58J	+0.03	-	+0.08	-	-0.05	-0.08	Variable Potentials
48	Incoloy 825 Commercial	--	+0.05	-	+0.06	-	--	--	"
49	Stellite		+0.13	-	-	-	--	--	"
50	Inconel	BS. 3076	+0.14	-	-	-	-0.17	-0.17	"

The period of test was again six months although some materials did not reach a steady potential in this time and were still changing in a +ve direction after a further four months.

Results

(a) *Static potentials*

The time taken for individual samples to reach a steady potential varied considerably, ranging from approximately one to 10 weeks.

Variations from the steady state potential for most metals were less than ±10 mV, but lead was still varying through ±80 mV after 40 weeks. Soft solder (60/40) and babbit metal both showed a steady increase in potential (towards +ve) over the test period, but 50/50 solder gave a steady result after one week. The onset of crevice attack between the mount and an Inconel specimen caused a change in potential from +140 to −200 mV in a few days.

The " steady state " potentials obtained are listed in the Table. They represent average readings and should not be regarded as absolute values for the metals concerned. Some agree closely with published figures, but others show large differences, especially the gunmetals. The higher potentials found for these alloys could explain their relatively good compatibility with monel and stainless steel, which has been observed in service. Materials such as austenitic stainless steel, Incoloys, Inconel and Stellite are difficult to place, because of their large range of passivated and active states, but experience has shown that they do not corrode preferentially when coupled to copper alloys and are therefore regarded as " noble " to these materials.

Variations from published data could be due to the long test period, variations in composition of the materials or differences in the sea water used.

(b) *10ft./sec. water speed*

The times taken to reach reasonably constant potentials at 10 ft./sec. were generally longer than those required for static conditions, extending in some instances to over 30 weeks. Deviations were also greater and several unavoidable pump stoppages caused large potential changes, but these recovered after several days.

The measured potentials are listed in the Table and a number of potential/time curves for both static and 10 ft./sec. potentials are shown in Figs. 1 to 6. These curves show that for the higher duty materials, such as aluminium bronze, the potentials recorded at 10 ft./sec. were higher (more +ve) than those recorded under static conditions. Also the potentials recorded for the lower duty materials such as brass and copper fell below their static potentials. The intermediate materials, such as gunmetal and Superston, reached various potential levels in between depending on their corrosion resistance or film forming ability. Mild steel, which could not be regarded as a high duty material, was the exception and showed a potential substantially higher than its static figure. A check of the literature[3] confirmed that this was consistent with previously recorded results. It should be noted that these results would not necessarily be the same for other water speeds and a table of static potentials could be misleading if used to predict possible galvanic corrosion in a system using moving sea water.

Conclusions

The tests indicate that metals take longer to form complete surface films and reach steady potentials than is indicated by previously published work in this field, especially in high speed sea water. Although some materials reached the so-called " steady state " in a few weeks, most required a minimum of 10, with others taking over 40. These times are a major departure from those referred to in earlier work where test periods of 14 days were regarded as adequate[1].

This time factor suggests that the risk of corrosion is greatest when a new sea water system is brought into full service without a " running-in " period at reduced water speeds to give the materials time to achieve their maximum corrosion resistance.

Materials which cannot form a stable protective surface film at a particular water speed fail by impingement attack and have potentials on the negative side of their static potentials. Copper, brass and silicon bronze, exposed to high speed sea water *i.e.* 10 ft./sec. are typical examples of this category. In the higher duty materials, aluminium bronze, aluminium brass and the higher copper-nickel alloys are typical of materials which can form
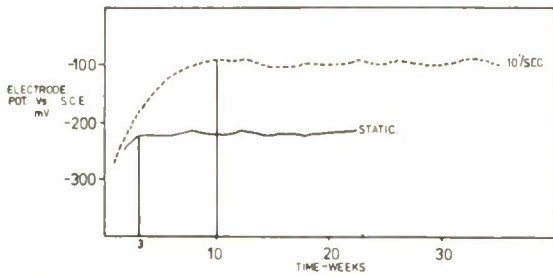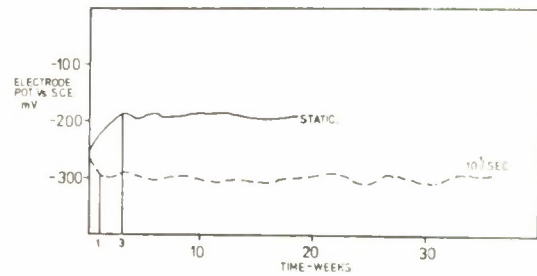
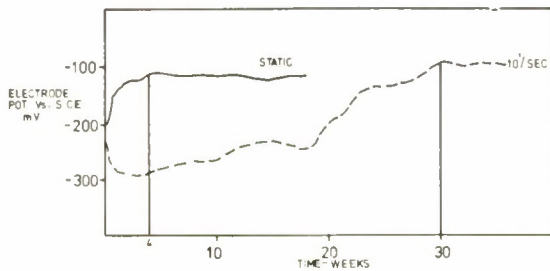FIG. 1. Aluminium Bronze (No. 21).

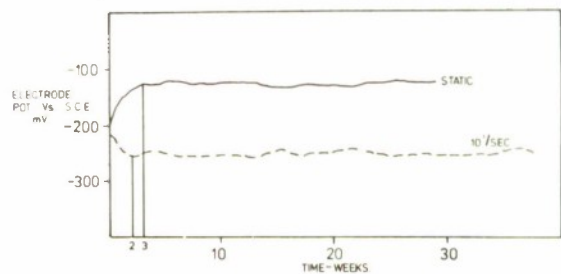FIG. 2. Gunmetal (No. 36).

FIG. 3. Superston 40 (No. 14).

FIG. 4. Naval Brass (No. 25).
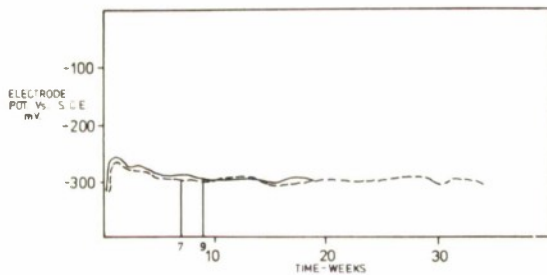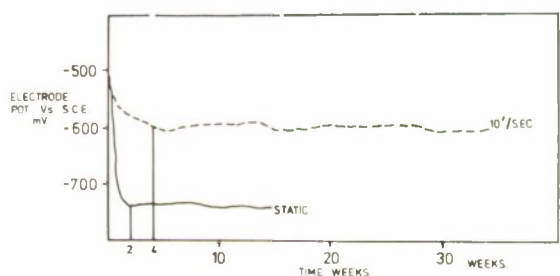

FIG. 5. Copper (No. 28).

FIG. 6. Mild Steel (No. 4).

surface films at this speed and show potentials on the positive side of their static potentials. At some higher water speed it is anticipated that these materials would also have their surface films stripped away and give correspondingly lower potential readings. Potentials, however, may continue to rise as this critical speed is approached.

This suggests that the threshold water speed, at which impingement attack commences, could be detected by a comparison of static and dynamic electrode potentials, failure being indicated by the dynamic potential falling below the static figure. Such a test, if not complicated by polarisation effects, could possibly be used to replace conventional jet impingement tests which do not correlate impingement resistance directly to water speed.

Future work

It is proposed to continue measurements of electrode potentials, especially of new or modified materials. When facilities are available, measurements will be made at a range of water speeds with the view of determining impingement thresholds as suggested above.

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THE POLLUTION OF PORTS

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Introduction   It must be recognised from the outset that there are two major problems which have to be faced when talking about pollution. First, there is the very real difficulty of defining precisely what is meant and secondly there is a dearth of specific information regarding the subject. Even in those areas where considerable effort and money has been expended, such as pollution by oil, the position still remains that there are more problems than answers. Another real danger is that the easily recognised forms of pollution, which are not necessarily the most important ecologically, tend to be investigated with greater thoroughness than the more serious problems arising from less obvious sources. This article deals specifically with the dangers of pollution of Ports and associated problems with an emphasis on the part played by the use of antifouling devices for ships and other structures. It has to be acknowledged straight away that as many ports are situated in estuaries aspects of pollution common to these areas need to be borne in mind.

Many definitions of pollution have been attempted [1, 2, 3, 4, 5, 6] none of which is entirely satisfactory, any more than the one given here. For the purpose of this article pollution will be taken to mean the introduction into the environment, by man or his agency, of materials which would not normally be found in that situation, or would not without his intervention be present in the same concentration.

The estuarine environment

There are many ways and many rates at which an estuary may become polluted and as a consequence no two are ever the same. The effect may be on the nutrients that are present, the Biological Oxygen Demand, or on the quantity of particulate matter or directly on the living organisms. There are also other forms of pollution which may be present such as inhibitors, poisons and heat. Even aerial pollution may have a profound effect when it is washed down by the rain through the surface drainage into the rivers and hence the estuaries. Perhaps most important of all is the pollution due to agriculture which often has a direct run off into the rivers.

Even in the absence of pollution, conditions in estuaries can vary very considerably from one year to the next. This is due to the fact that the distribution, seasonality and abundance of epifaunal species are dependent on such factors as salinity, temperature, turbidity and water movement. It is therefore extremely difficult to assign the precise role of any pollutant in the estuarine condition unless controlled experiments are carried out to pinpoint the effect. They should also include studies to determine whether one pollutant is lowering the threshold response to another or to determine any synergistic effect.

Some ports are partially or practically enclosed and in this situation the forms of pollution may be more limited but those present are likely to reach far higher limits than in the estuarine condition. It has been calcu-

lated[7] that in enclosed basins with many ships alongside, a copper concentration of 1 ppm might be realised which would prove fatal to many forms of marine life. With the advent of the larger tankers and container ships there is a definite move towards constructing ports at exposed sites along the coast. This tendency may well have a beneficial effect upon our estuaries.

Oil Pollution

Oil pollution is one form which it is not proposed to discuss at any great length with regard to ports. It must be said, however, that there is an increasing risk for ports to be subjected to accidental spillage or spillage due to collision. Usually recovery to a single spillage is good but some evidence suggests that repeated oilings of salt marsh vegetation has a deleterious effect, *e.g.* from eight to 12 coverings results in considerable change taking place[8]. Recovery under these conditions is slow and where large bare areas of mud have been produced considerable change can take place due to erosion. From the biological point of view the most serious effects of oil pollution are experienced by sea birds although reports of adverse effect upon molluscs, barnacles and species of red algae etc., are well known. The age of the oil also has an important effect in so far as fresh oil contains the lighter fractions which disappear on ageing[8]. Another aspect of oil pollution is that it has been noted that persistent biocides such as D.D.T. become concentrated in oil slicks[9].

Accidental spillage of toxins

One of the best examples of the adverse effect of pesticides comes from the Yacht Marina at Birdham Pool, Chichester Harbour[10]. In the late 1960s phorate was being sprayed from aircraft on to fields near the pool which was carried by the wind on to the water. The grey mullet previously introduced to scavenge the refuse from the yachts had flourished successfully up to that time. The result was that they died off in large numbers as well as other fish in the area. A spillage of insecticides in the Moroccan Port of Mohammedia was reported to have been responsible for the death of large numbers of fish and seabirds[11]. Another accidental discharge of pesticides occurred at La Coruna, Spain, in 1971[12].

Compounds used in antifouling paints

With the severe penalties exacted by the fouling of ships, *viz.*, extra fuel costs, loss of speed, loss of earnings and the cost of remedial action, it is not surprising that ship owners are anxious to have the bottoms of their ships protected with efficient antifouling agents. As far as the very large tankers and container ships are concerned it is highly desirable that they be kept at sea for as long as possible. It is not only the enormous cost involved in docking but the fact that there is a shortage of geographically distant ports. This serves to reinforce the need for really effective antifouling devices which will last for long periods of time. Methods of underwater painting would be useful but they may well increase the risk of pollution.

The most commonly used antifoulant is copper (I) oxide although many other compounds have been tried including others of the same metal. The latter are less effective and are not therefore in general use. Mercury compounds such as mercury (II) oxide and (I) chloride are even more effective than copper (I) oxide but because of cost they were usually added to copper paints as " boosters ". They are no longer used for antifouling purposes because they first of all represent a health hazard in the preparation of the outer bottom for repainting and secondly they have been implicated as environmental pollutants. Since some forms of bacteria are capable of converting the inorganic compounds into methyl mercury, the risk to man is increased through food chains. Other inorganic metallic compounds including zinc oxide have been found to be considerably less effective than copper (I) oxide. Arsenic being an accumulative poison has not gained general acceptance as an antifouling agent and in any case it is not very effective in its inorganic forms. Some organic arsenicals have nevertheless been tried. It is worth recording that 10, 10′, oxy-bisphenoxarsine proved to be an effective antifouling agent. The Dow Chemical Company, however, carried out a number of tests on algae and found that the compound could be concentrated as much as 1,000 fold by these organisms. Because of the implications of the environmental hazard they withdrew from the market a potentially good antifouling compound[13].

The bis tributyl tin compounds were found in laboratory tests to be about two orders of magnitude more toxic than copper (I) oxide. They are also degradable which led to their initial use in agriculture as fungicides[14]. They have not been used to the extent which at one time appeared possible because of their inability to control the brown alga *Ectocarpus*. They have been used to " boost " copper paints.

The triphenyl lead and tributyl lead acetates have been found to be reasonably effective as antifouling agents but since lead is no longer acceptable in the environment their use is being curtailed.

Because of the wide range of its effectiveness copper (I) oxide is the usual toxicant included in antifouling paints. Unfortunately, it loses its toxicity when the paint is dried out and has to be " boosted " with other compounds for some purposes. This is particularly so where there is a large difference in depth between the ballast and load lines.

To remain effective copper has to leach out from the antifouling paint at approximately $10\mu g/$sq cm/day. At this rate $0\cdot1g/$sq m of copper is discharged into the water per day and a ship of 10,000 sq m outer bottom would be releasing about 1kg/day[7]. Under normal conditions in an estuary or port, with a good exchange of water, these quantities of copper would not present a hazard as an environmental pollutant. It is stated[6] that man can take as much as 100mg of copper/day in food without any danger whatsoever. It is not usual for copper to become an environmental pollutant, except in mining areas, and even here adaptation has occurred in some species to withstand the high concentrations.

The possibility does exist, however, that copper could be regarded as an environmental pollutant in enclosed docks with a high density of shipping and practically no exchange of water[7]. If 10 ships of 10,000 sq m underwater area were enclosed in such a dock for 100 days 1 tonne of copper would have accumulated. In a dock of about 1,000,000 cu m the concentration would be about 1 ppm. This concentration of copper is effective in killing off the larvae and spores of sedentary organisms but would not constitute a direct hazard to a large number of higher organisms and man. It would of course upset the food chains

giving rise to an indirect effect upon higher forms. The chances are that such an enclosed basin would have other pollutants carried into it of a more serious nature and would be considerably polluted on that account alone. It is also of significance that when copper is allowed to accumulate in the water adjacent to an antifouling paint relatively low concentrations have a stifling effect upon the leaching of further copper, even at concentrations as low as $0\cdot1$ ppm.

Another way in which copper could constitute a hazard is in the disposal of arisings from docking. It has been estimated[7] that 10-20% of the composition supplied for a ship falls to the dock bottom and that a well coated ships bottom has approximately 1kg of copper per 40 sq m left in the paint which is blasted off and falls to the bottom of the dock. Arisings are often dumped at sea in deep water where over a long period of time they may accumulate on the sea bed. The remains which are not removed from the dock will contaminate the water when the dock is filled. There is no direct evidence on this point but the marine growths in the vicinity of the discharge pipes, in some docks at least, indicate that there is no serious pollution from this source.

Sewage sludge dumping in the Firth of Clyde has been carried out for many years. The sludge has been contaminated with a variety of heavy metals. Copper together with lead, tin and zinc have a strong association with organic matter. The level of copper, however, in the whelk (*Buccinum*) from the vicinity is lower than it is in the Irish Sea[15]. The range of copper in sediments is from about 20 ppm in low copper areas to more than 4,000 ppm in heavily polluted estuaries[16]. Nevertheless, it is worthy of note that in the United States there are local ordinances, in Newport News, Virginia, for instance, that prohibit the disposal of paint scrapings in the harbour. In Holland[17] where the level of copper in coastal waters can fluctuate between $2 - 15\mu g/1$, it has been shown that there is virtually a linear relationship between the living organisms and the surrounding water. In some instances the margin between safe limits for copper sensitive species and the prevailing copper content appears to be small.

Before leaving antifouling paints it should be mentioned that the chlorinated diphenyl compounds have been used as plasticisers in

many of these compositions. It is encouraging, from an environmental point of view, that Monsanto Chemicals have withdrawn all its range of chlorinated di- and ter-phenyls because of their suspected involvement in environmental pollution. PCB compounds have apparently been responsible for the high incidence of deformities[18] in, as well as, the death of a large number of sea birds.

Conclusion

Copper containing antifouling paints do not appear to constitute an environmental pollution problem.

It will be necessary to ensure that compounds used to " boost " copper based paints do not give rise to an environmental hazard.

It will also be necessary to ensure that any new compounds developed as antifoulants do not give rise to a pollution problem.

The indications, at present, are that on the whole industry is maintaining a watchful eye on the pollution problem and certainly in two instances have acted very responsibly.

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THE C.S.C.F.E. ESSAY COMPETITION

The Civil Service Council for Further Education offers a prize of £50 (and possibly other prizes) for an essay dealing with some aspects of further or adult education. Entries should not have been published previously or substantially embody material which has been published previously. They should be typewritten, and be sent to the Secretary of the CSCFE at 11 Belgrave Road, London SW1V 1RB, by 15th March, 1974. Copyright in winning entries (which may be published) will pass to the CSCFE.

The essay should be on one of the following subjects:

(a) The Russell Report said that " the concept of a *permanent education* envisages a society in which the whole lifelong learning needs of all citizens would be taken as the field with which the national education system is concerned ". How might this concept be interpreted for civil servants ?

(b) An account and an assessment of the continuing validity of the ideas of some important figure in the field of adult education in the 20th century.

(c) The place of physical education in the development of the individual.

THE EFFECT OF INCREASED GAS DENSITY UPON ALVEOLAR VENTILATION/PERFUSION AND GAS EXCHANGE DURING EXPIRATORY FLOW-LIMITED EXERCISE

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Introduction. Circulatory factors are generally considered to be the prime determinants for limiting oxygen supply to the tissues during work at 1 atmosphere absolute (ata). Linnarssen and Fagraeus[5] have shown that maximal aerobic capacity can be increased somewhat at increased ambient pressure due to increased oxygen saturation of arterial blood, but that the increase in work capacity becomes restricted by increased gas density at pressures in excess of 3 ata. Our previous studies[9, 10] and those of Wood, *et al.*[14] have demonstrated that physical work at increased ambient pressures may be limited by ventilatory restriction due to the effects of increased gas density upon effort-independent expiratory flow. Moreover, our results indicated that such a ventilatory restriction in the face of increased gas density involves the diminution of gas flow in the small airways upstream from the equal pressure point as defined by Mead, *et al.*[6]

According to Mead[7], the regional distribution of gas in the lung is, under normal circumstances, determined by the vertical gradient of pleural pressure from top to bottom of the lung even at maximum expiratory flow. Wood, *et al.*[15], from their studies of ^{133}Xe lung washout in sulphur-hexafluoride (SF_6), suggested that mechanical time constants for lung emptying were sufficiently prolonged at a relative gas density of approximately 5·0 to affect the distribution of labelled gas. Moreover, at increased flow rates such an effect should be more marked still. Although these observations are not in accord with those made by Cruz, *et al.*[2], Vorosmarti and colleagues[11], Miller (unpublished data) and Miller and Glaister (unpublished data) using widely differing approaches, the implications of impairment to gas exchange during heavy exercise at increased gas density warranted the present set of studies.

Using a non-invasive method for the estimation of pulmonary capillary blood flow (Qc)[13], we investigated the effect on gas exchange on overall VA/Q and on regional distribution of VA/Q of performing very heavy work breathing air at 1 ata, and breathing O_2 20%, 80% SF_6 mixtures, having a relative gas density of approximately 5·0.

Materials and Methods

The experiments were performed by six healthy subjects, five males and one female, ranging in age from 24 to 38 years. We initially measured maximum voluntary ventilation (MVV), in each subject breathing both air and gas mixture containing 20% O_2 and 80% SF_6, using a wedge spirometer (Oxford Instrument Company) coupled *via* appropriate voltage division to a Minograf 81, 8 channel polygraph.

We measured pulmonary ventilation (Ve), oxygen consumption (VO_2), and CO_2 production (VCO_2) in each subject, during the final one to two minutes of each experimental period, primarily by the open circuit Douglas bag method, at rest and at very heavy but submaximal work breathing the SF_6, O_2 mixture. On the basis of previous experience with the same subjects performing graded exercise breathing air[13], we selected the heavy but submaxial work load settings so that the pulmonary ventilation required should be about equal to each subject's measured MVV

when breathing the SF₆ mixture. In order to facilitate our carrying out the number of experimental procedures required during each exercise period, we reduced the load-setting by 30-50 watts for each subject, to enable a sufficient period of work to be performed without severe hypercapnia when breathing SF_6, O_2. Gas analysis of O_2 and CO_2 was carried out using a quadrupole respiratory mass spectrometer (Twentieth Century Electronics 0806 Residual Gas Analyser). Intermittently, throughout each experiment, breath-by-breath analysis of O_2 and CO_2 was made to determine end-tidal P_{CO_2} (Pet_{CO_2}) and Pet_{O_2}.

Control measurements were made in each subject for rest and the same work load settings breathing air. In addition, three of the subjects performed experiments at moderate work loads breathing both the SF_6, O_2 mixture and air. Heart rate was monitored throughout by means of resistive chest electrodes coupled to the recorder *via* an appropriate amplifier.

Using a modification of the technique described by Winsborough[13], and a modification of the technique developed by Cander and Forster[1], we measured cardiac output (Qc) both as a function of CO_2 exchange across the lungs, and as a function of N_2O uptake. By means of the mass spectrometer both measurements were made simultaneously, with appropriate voltage division for recording purposes, and electronic correction for N_2O artifacts in analysing CO_2 in the presence of N_2O. Fig. 1 depicts the experimental set-up used to obtain the data for cardiac output estimation. These measurements were made during the final third of the experimental period normally sustained for longer than six minutes, and, in themselves, accounted for no more than 30 seconds of the period.

An approximate value for alveolar ventilation (VA) was calculated from standard gas-exchange equations, employing the assumption that, at least when breathing air, Pet_{CO_2} approximately represents Pa_{CO_2}, as shown by Winsborough[13]. Despite some technical difficulties with CO_2 analysis during many of the experiments, due to the inadvertent contamination of the mass spectrometer with mineral oil, we, nonetheless, obtained several sets of comparative cardiac output data between air and SF_6, indicating no significant impairment to CO_2 exchange across the alveolar capillary membrane during SF_6 exposure. Moreover, we were able to validate our calculations of Qc by the simultaneous measurements of Qc using the N_2O method. It is justifiable to assume, therefore, that the errors inherent in equating Pet_{CO_2} with Pa_{CO_2} are no greater during SF_6, O_2 breathing than when breathing air. For comparative purposes only, we computed overall VA/Qc from the data obtained.

During the middle third of each experimental run a pair of single breath wash-in, wash-out manoeuvres was performed, inspiring discrete 100 ml boli of 50% argon and 50% N_2O from residual volume. The effect of SF_6 on the distribution of alveolar gas in relation to air was studied on the succeeding expirate by the simultaneous analysis by mass spectrometer of the argon and N_2O. Expired volume was measured by means of the wedge spirometer.

The experimental arrangement is shown in Fig. 2. The 100 ml bolus of gas was injected into the mouth at residual volume and inspired slowly in the first of the pair of manoeuvres to total lung capacity. In the second manoeuvre the bolus was inspired rapidly. The succeeding expirate was made into the
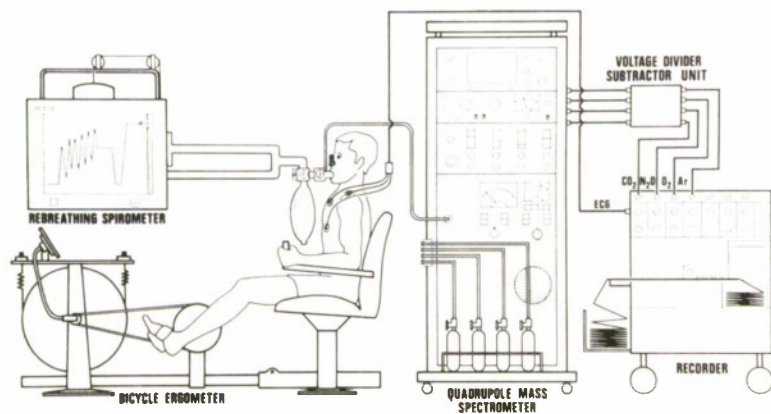

FIG. 1. Experimental equipment and lay-out used to obtain data for cardiac output estimation and overall N_2O uptake rate.
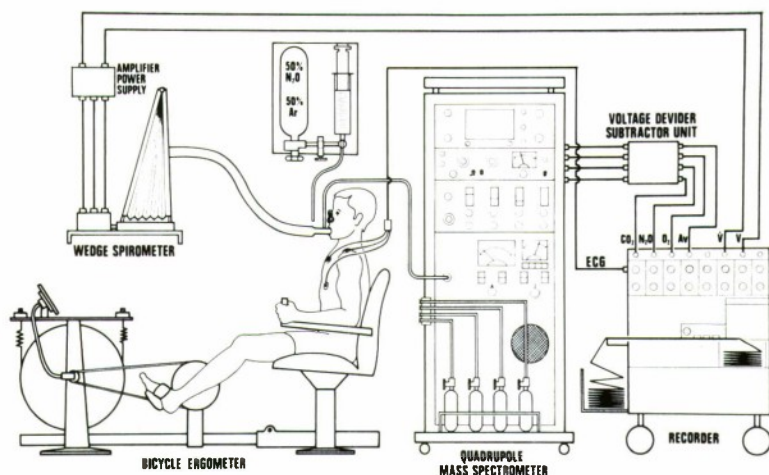
FIG. 2. Layout of apparatus employed in single breath wash-in, wash-out technique.

spirometer at about 0·5 L/sec in both manoeuvres. Fig. 3 shows typical data recorded in one subject from a slow in, slow out manoeuvre at rest breathing air.

Argon concentration and the ratio of N_2O to argon concentrations were plotted as functions of expired lung volume with allowance made for instrument delay, to obtain alveolar gas plateaux. Both labelling gases contained in the inspired bolus have approximately the same molecular weight ($N_2O=44$; $Ar=40$), and are therefore likely to be carried to the same parts of the lung. Indeed, each change in concentration seen on the record for one gas was mirrored exactly in time by a similar change in concentration for the other. Nitrous oxide, however, is a great deal more soluble than argon, and, during the time of the manoeuvre, some N_2O is taken up by the blood passing through the lungs.

Since the expired argon concentration represents, at least in the lower half of the vital capacity, the regional distribution of inspired gas[3], and is mirrored in this by the expired N_2O concentration, the ratio of N_2O to argon concentration represents the regional distribution of blood taking up N_2O. The slope obtained from the ratios at different expired volumes can be depicted, at least in the latter part of the expirate, in relation to the overall N_2O uptake which was determined at constant lung volume during the cardiac output estimation manoeuvres. We found, in practice, that the overall N_2O uptake slope like its equivalent CO_2 output slope [13], is primarily dependent upon pulmonary capillary blood flow provided that the measurement is made at a constant lung volume, the actual magni-

tude of the volume being unimportant at least, between FRC and one litre below TLC.

Ratio values falling above the mean overall N_2O uptake slope indicate that less N_2O was taken up at that lung volume than average, implying that the part of the lung emptying predominantly at that particular lung volume had been relatively poorly perfused. On the other hand, ratio values falling below the mean slope imply that the part of the lung
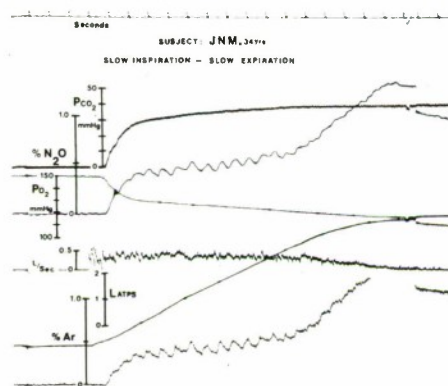
FIG. 3. Sample of data obtained by a slow inspiratory wash-in, followed by a slow expiratory wash-out manoeuvre, where a 100 ml bolus of 50% Ar and 50% N_2O was fully inspired from RV.

providing most of the expirate at the lung volume in question, had been relatively better perfused than the average, as more N_2O was taken up than the average. In this way, relative differences in ventilation and perfusion at different lung volumes were studied at rest and during work breathing both air and the SF_6, O_2 Mixture.

FIG. 4. Change in VE with increasing VO$_2$ in two subjects breathing air and 80% SF$_6$, 20% O$_2$.

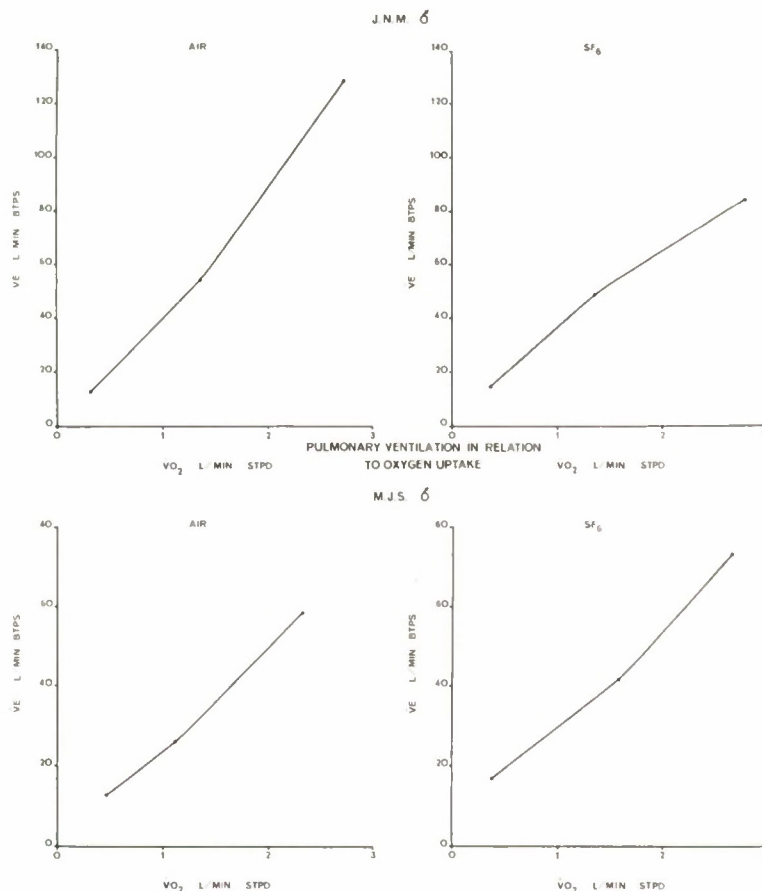Our selection of the levels of severe exercise to be performed by each subject breathing the SF$_6$, O$_2$ mixture proved to have been too conservative for at least three of the six subjects, whose VE measured during the period fell somewhat short of their MVV values recorded for the SF$_6$ mixture. One subject (MW), indeed, was able to reach her maximal aerobic capacity breathing the SF$_6$ mixture, without being encumbered by ventilatory problems. Two of the subjects, only, required VE levels that were hampered by the increase in gas density during the severe exercise period in question.

Table 1 shows the ventilation rates, oxygen uptake and cardiac output measurements made on two subjects at rest, moderate exercise and severe exercise, breathing both air and SF$_6$, O$_2$ mixtures. The older subject (JNM) was ventilating his lungs at or near his MVV during severe exercise breathing the

SF$_6$ mixture, with concomitant alveolar hypoventilation and hypercapnia. Cardiac output (Qc) for the same level of VO$_2$ was slightly greater when breathing SF$_6$, O$_2$, than when breathing air. Calculated overall VA/Qc showed a characteristic increase during work, with a marked decrease during SF$_6$, O$_2$ experiments in relation to the air control data, especially during the severe work. In addition, VA/Qc appeared to be somewhat diminished in this subject during moderate work breathing the SF$_6$, O$_2$ mixture.

The data obtained from the other subject showed no such evidence of ventilatory limitation. His resting measurements breathing SF$_6$, O$_2$, like the other subjects, showed a marked degree of pulmonary hyperventilation with hypocapnia, due, perhaps, to the heady euphoria observed after several minutes of breathing the SF$_6$ mixture. The exercise results obtained, however, showed a uniformly

TABLE 1.

Ventilatory and gas exchange data from two subjects: one (JNM), performing severe work at a level close to his MVV; the other (MS) maintaining a wide margin of ventilatory sufficiency.

Experiment	V_{O_2} L/min STPD	V_E L/min BTPS	MVV L/min BTPS	$PetCO_2$ mmHg	CALC V_A L/min BTPS	Qc N_2O L/min	CALC V_A/Qc
Subject MS 24 years							
Resting on Air	0·465	12·33		41·0	7·831	8·20	0·95
Resting on 80% SF₆	0·356	16·44		25·47	12·88	9·37	1·37
Moderate Exercise on Air	1·11	25·80	Air: 240	39·87	19·33	11·60	1·655
Modcrate Exercise on 80% SF₆	1·59	41·33	80% SF₆ 150	39·70	36·06	16·1	2·24
Severe Exercise on Air	2·348	57·33		42·1	44·13	20·60	2·14
Severe Exercise on 80% SF₆	2·65	73·1		40·36	54·35	24·89	2·18
Subject JNM 34 years							
Resting on Air	0·320	12·44		34·73	10·16	4·8	2·1
Resting on 80% SF₆	0·357	14·23		27·0	14·23	6·73	1·88
Moderate Exercise on Air	1·362	54·18	Air: 198	37·12	40·64	11·25	3·61
Modcrate Exercise on 80% SF₆	1·357	49	93·5 80% SF₆	33·36	41·29	14·7	2·81
Scvere Exercise on Air	2·725	129·0		31·1	76·86	23·6	3·26
Severe Exercise on 80% SF₆	2·80	85·14		48·37	45·5	21·5	2·1

eucapnic state throughout. Calculation of overall VA/Qc showed a consistent increase with increased VO₂, except during the resting experiment breathing SF_6, O_2, where hyperventilation affected the calculation.

Fig. 4 shows VE in L/min BTPS, depicted graphically as a function of VO₂ in L/min STPD, in each of the two subjects performing the experiments breathing air and 80 : 20, SF_6, O_2 mixtures. The limitation to pulmonary ventilation when subject JNM breathed the

SF_6 mixture during very heavy work is clearly shown. No such limitation is demonstrable in the other subject's data.

Of the pairs of single-breath manoeuvres performed by each subject using argon and N₂O boli as indicators of gas and blood distribution, the fast inspiration followed immediately by slow expiration was found to be the more reproducible at high exercise loads because of its shorter duration. Fig. 5 depicts the results obtained from the two subjects at
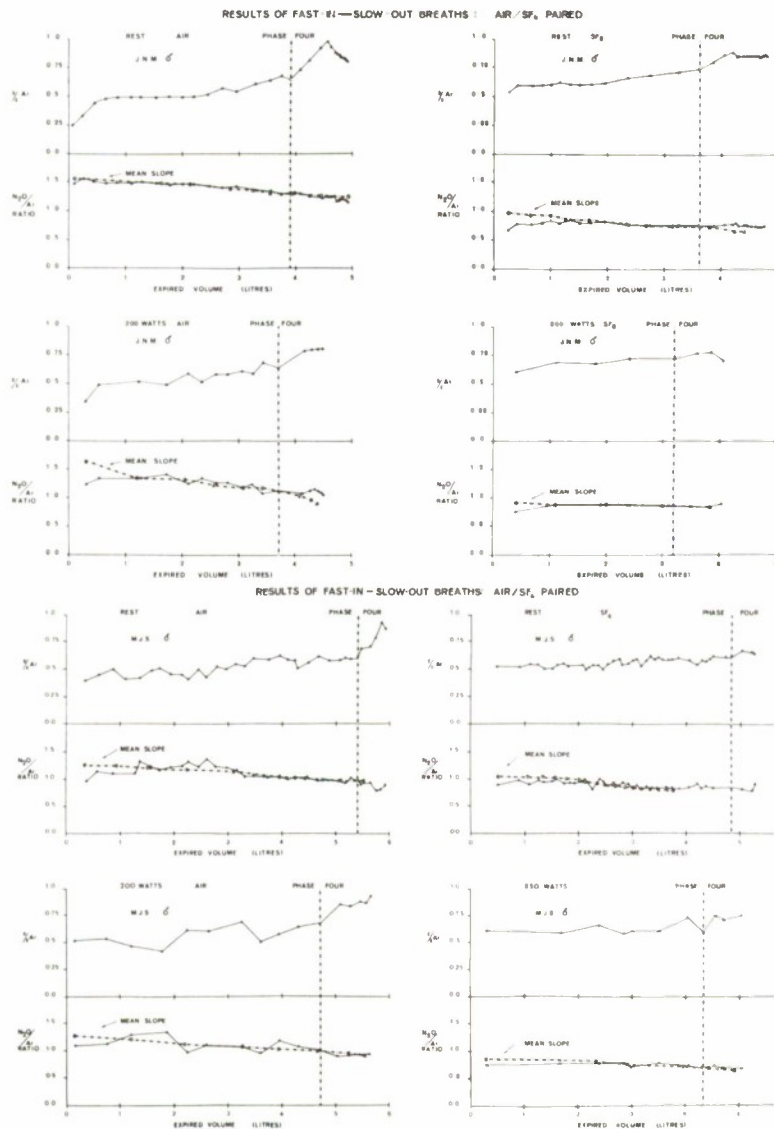

FIG. 5. Alveolar Ar plateaux and N₂O/Ar ratios obtained in two subjects at rest and during severe exercise when breathing air and 80% SF_6, 20% O_2.

rest and during heavy work breathing both air and the SF_6 mixture. Each variable is shown as a function of expired lung volume. The alveolar argon plateaux obtained, demonstrated characteristic phase IV elevations at relatively low lung volumes in five of the six subjects. It is significant that subject JNM managed to elicit reproducibly, marked phase IV peaks at higher lung volumes than any other subject. Moreover, the so-called "closing volume", that is, the lung volume at which the phase IV peak begins[8], in that subject appeared to be more greatly influenced by both heavy work and increased gas density than in any other subject.

The ratio of N_2O to argon, however, throughout each expirate varied little from the mean ratio calculated from the overall uptake of N_2O by pulmonary capillary blood, that measurement being made during the Qc estimation manoeuvres. Neither heavy exercise, nor increased gas density appeared to affect these results in each subject. Even in subject JNM, who presents evidence of small airways obstruction, inferred from his high "closing volumes", the N_2O/Ar ratio remained stable in relation to the mean value even when exercising in the face of effort-independent expiratory flow limitation.

Heart-rate, monitored throughout the experiments in each subject, was found to be within physiological limits for each level of VO_2. However, some slight increase in rate in each subject was found both at rest and exercise during the SF_6, O_2 experiments. Breathing frequency was affected more variably.

Discussion

With the advent of the quadrupole respiratory mass spectrometer simultaneous multiple inert gas washout techniques have become possible. In order to make simultaneous measurements of CO_2 (mass 44), and N_2O (mass 44), we utilised the "cracking pattern" of N_2O to nitric oxide (NO-mass 30). We amplified the mass 30 signal from a calibration mixture of CO_2-free N_2O to equal the mass 44 signal from N_2O alone, and then subtracted the mass 30 from mass 44 signals, thereby allowing the analysis of CO_2 without any artifacts derived from the presence of N_2O. Nitrous oxide itself, was analysed by its mass 30 fraction. This technique, even for N_2O analysis of less than 1% concentration, was

within a reasonable signal/noise level for the instrument. Sulphur hexafluoride, in the high concentrations used in these experiments, reduced the response characteristics of the mass spectrometer to some extent, but they were still well within acceptable limits.

The hypothesis, that a sufficient increase in upstream airways resistance during effort-independent expiratory flow may prolong the time constants for regional lung emptying to a point where the regional distribution of gas in the lungs is affected, is highly attractive, especially as a model of chronic obstructive airway disease. To this end, the evidence advanced by Wood and his colleagues[15], indicated that such was the case when breathing SF_6, O_2 mixtures. To date, however, no other workers using different techniques have been able to confirm their findings. Indeed, the bulk of the evidence accumulated so far, tends to demonstrate the reverse: that increased turbulence within the airways at increased gas density enhances mixing and thus reduces stratification effects[2].

It is possible, however, that as upstream airway resistance increases, relatively less gas leaves those regions having a higher small airways resistance, thereby causing them to inflate to a higher end-expiratory volume. If such be the case, then those regions would be breathing higher on their compliance curve, thus offsetting the effect on regional time constants, by decreasing the compliance as the resistance increased. The net effect could, therefore, be minimal.

That subjects breathing at effort-independent expiratory flow levels increase their functional residual capacity has been clearly demonstrated at increased ambient pressures by Miller *et al.*[9,10] and Wood *et al.*[14]. This observation does not necessarily imply that alveolar gas trapped by increasing FRC in such circumstances, is distributed other than along the normal gradients imposed by the vertical distribution of pleural pressure. What is likely, however, is that some redistribution may occur with relatively more gas being trapped in those regions of the lung normally better ventilated during exercise; for it is those regions which undergo the greatest volume change in tidal breathing. The net effect of a relative decrease in alveolar ventilation in such regions would be a relative decrease in VA/Q, as those regions themselves, tend to be better perfused.

We expected our data to show, especially at rest, that the gas leaving the lung at relatively high lung volumes would come from better perfusion regions, and the gas observed later in the breath would come from relatively poorly perfused parts. During severe exercise we expected that the N_2O/Ar ratio would increase in regional perfusion, with little variation throughout the breath in $N_2O/$. At about the mean ratio, except when VA was reduced at increased gas density. Our results indicate that such expectations were justified, except in the case where exercise ventilation was limited at increased gas density by effort-independent expiratory flow. These results showed that, despite some reduction in VA in subject JNM, the regional uptake of N_2O was similar to the overall uptake, indicating that the greatest reduction in VA had probably occurred in regions normally less well perfused. Alternatively, the reduction in overall VA may have been offset regionally by a compensatory increase in perfusion. In either case, the regional distribution of gas exchange was not functionally altered in that subject, being indistinguishable from that seen at lower levels of work, at lower gas density or in other subjects. Neither was it altered in the subjects whose ventilation was not limited by the increase in gas density.

We conclude, therefore, that increased gas density *per se*, is sufficient to alter the regional distribution of alveolar gas with respect to blood, even during expiratory flow-limited work.

Acknowledgments

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MINISTRY OF DEFENCE FUEL CELL DEVELOPMENTS

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Introduction

The fuel cell is an electrochemical device in which the chemical energy of a fuel is converted directly to electrical energy by reaction of fuel and oxidant at appropriate electrodes separated by an electrolyte. The basic principles associated with this technique of power generation have been described in this journal[1].

The characteristic of direct energy conversion provides two main advantages in the use of a fuel cell power source; high efficiency because of its independence of the Carnot limitation and low noise emission level. In addition, low maintenance can be expected because there are no highly stressed moving parts, maintenance of the rotating ancillary components necessary for supply of reactant and circulation of electrolyte being achieved by replacement. With these advantages, fuel cells have potential application in military equipment and in 1965 a research programme was initiated in the Ministry of Defence aimed at the advancement of small transportable fuel cells and the demonstration of their feasibility for military application. The programme, which ran until late 1972, was carried out at the Admiralty Materials Laboratory on an inter-service basis and included as part of the activities the engineering development of low temperature hydrazine/air and hydrogen/air fuel cell power plants and associated equipment. This progressed through a series of breadboard systems in the initial stages of the programme to the production of more fully engineered research models. This article reviews the design, construction and performance testing of some of the power plants and hydrogen generating equipment produced.

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Hydrazine/Air Fuel Cell Systems

Hydrazine, used in fuel cells as the monohydrate, is a liquid fuel, synthetically produced and relatively expensive but readily oxidised electrochemically. Initially it was considered that hydrazine fuel cells could find application at low power levels and the research was aimed at systems of the order of 50 W. Early in the research programme, however, a fuel cell was selected as the preferred power source for the *Cymbeline* mortar locating radar set and a prototype 750 W hydrazine fuel cell power plant was constructed in a project development by the then Ministry of Technology for this equipment. By the time the prototype was built the power requirements of the radar set had increased. As it was not possible within the time scale to produce a fuel cell which would give the required power within the envelope allowed for the power source, further development was abandoned.

Because of the possible application of fuel cells in such equipment, effort in the later stages of the hydrazine research programme was aimed at power plants in the $1 - 1 \cdot 5$ kW range. The units were based on 40-cell alkaline electrolyte fuel batteries developed for the Ministry of Defence by Shell Research Limited. In these batteries nickel minimesh was used as the fuel electrode. For improved performance the surface area of the nickel was extended by deposition of a mixture of nickel and aluminium powders on to the surface and subsequent leaching of the aluminium with alkali. The air electrode consisted of a sheet of microporous PVC metallised on one side for current collection and coated on this face with a carbon supported noble metal catalyst[2].

The first fuel battery produced in 1968 had a nominal output of 1 kW and in a continued research programme improvements were made

to the fuel electrode resulting in the construction of a 40-cell battery of equal size in 1970 which produced in excess of 2 kW. The development of these batteries was described at the 5th Intersociety Energy Conversion Engineering Conference in 1970[3]. In Fig. 1 the average cell performance of the batteries is plotted together with the value for a 32-cell unit constructed for the MOD at an earlier stage and shows the substantial improvement achieved in the development programme.

The nominally rated 1 kW battery was incorporated into a self-contained power plant designed and built at AML[4]. As the construction of this unit was largely an exercise to gain experience for the subsequent design of a more advanced unit the system was built in a simple form. The power plant is illustrated in Fig. 2. The structure and main components were manufactured from polypropylene and simple voltage regulators were used to drive the air and electrolyte pump motors. The fuel concentration was maintained at about 0·45 M hydrazine, necessary for maximum efficiency, by an electrochemical monitor/controller developed at AML[5]. Following establishment of the system, this power plant was operated with a fuel battery which initially produced 1·3 kW gross for a period of 130 hours in a test programme. At the end of this period the power plant was producing 1·1 kW gross at 25 V with some 225 W being consumed by the ancillaries.

The 1970 fuel battery was engineered into a power plant by Lucas Aerospace Limited to an AML target specification[6]. The aim was to produce a robust, compact research model power plant of 1·5 kW output in the range 21·6 - 29·0 V. This power plant will be used to describe in some detail the main subsystems involved in the construction of this type of equipment. The fluid system schematic is shown in Fig. 3. Reaction air is drawn by a sliding vane compressor, driven directly by a 24 V dc motor under the control of a voltage regulator, through a filter, through the electronic control package and drive motor for cooling purposes and through a soda-lime container to reduce the carbon dioxide content of the air to a low level. The air, at $3·5$ dm^3 s^{-1} and 16 kN m^{-2}, is fed to the fuel battery and then to the top compartment of a vortex gas/liquid separator before exhausting to atmosphere. The 7 M potassium hydroxide electrolyte supplied at $0·08$ dm^3 s^{-1} by a positive displacement pump, Vee-belt driven from the air pump shaft, is first passed through an air cooled heat exchanger and then through a 3-way valve to the fuel battery. After passing through the battery the electrolyte, now a frothy mixture containing product nitrogen gas, is fed to the centre compartment of the gas/liquid separator. The separated gas is swept by the air and the electrolyte returns to tank. The drain valve illustrated has two exit ports, one to the fuel battery and one to the tank. Provided air pressure is supplied to the valve a diaphragm seals the exit to the tank. At shut-down or in the event of failure of air supply, the diaphragm lifts and the electrolyte contained in the fuel battery drains back to tank, the optimum shut-down condition. The hydrazine monohydrate fuel is fed to the inlet of the electrolyte pump through a solenoid valve under the control of a fuel monitor. The fuel concentration sensor is located in a loop between the tank and the pump.

The power plant is shown in Fig. 4. The controls are housed in a detachable front compartment. Access to the soda-lime container and electronic cards is available through removable panels in the front of the equipment. The heat exchanger uses the whole of the cross-sectional area at the rear. The overall dimensions of the equipment are 405 mm high $\times$ 405 mm wide $\times$ 900 mm long and the operational weight with 9 dm^3 fuel, sufficient for more than four hours operation is 119 kg. At 1·5 kW this gives a specific weight of 79·3 kg kW^{-1} and a specific volume of 0·098 m^3 kW^{-1}.

Control of the power plant is fully automatic, the start-up sequence being initiated by a single push-button switch which connects an auxiliary battery supply to the pump motor and other ancillaries. When the fuel battery reaches 28 V (a no-load voltage of 36-38 V
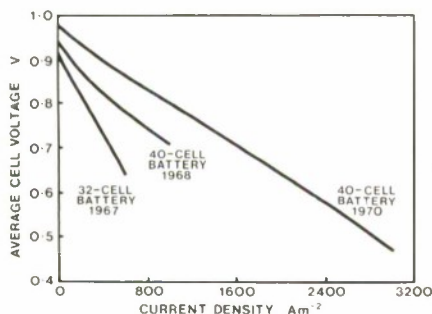

FIG. 1. Average cell performance of Shell Research Limited hydrazine/air fuel batteries.
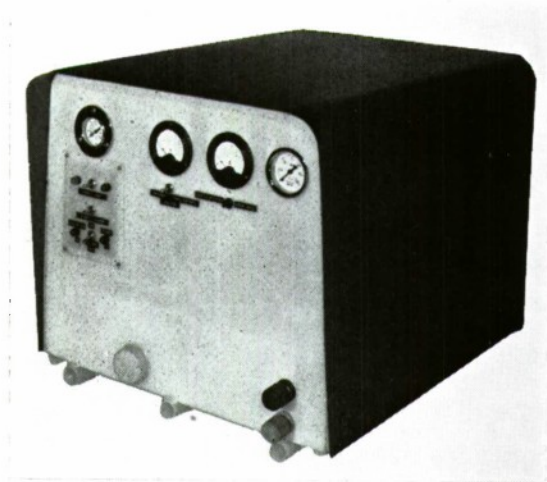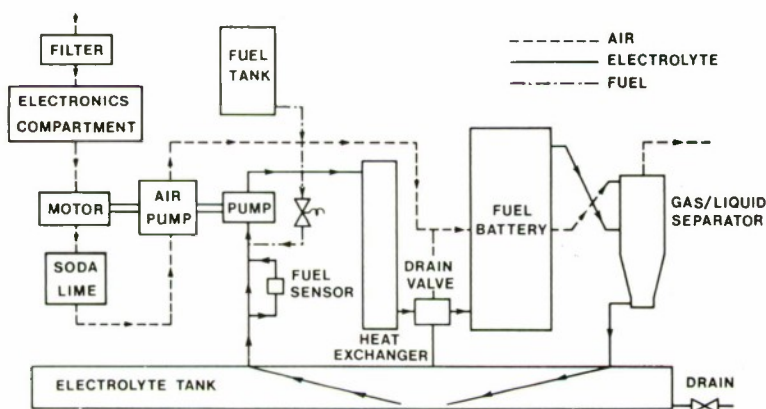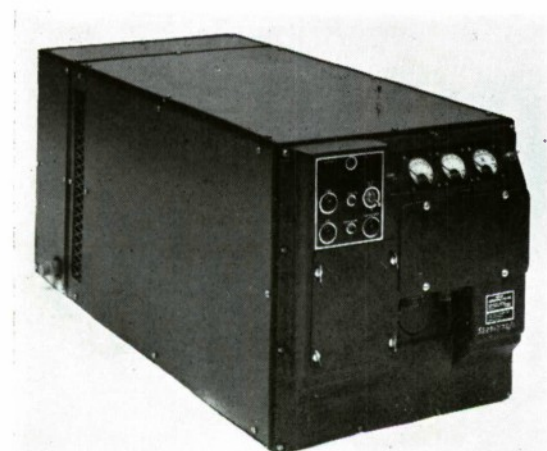
FIG. 2. 1 kW hydrazine/air fuel cell power plant.

would be expected for this battery) the internal power requirement of the system is transferred to the fuel battery and recharging of the auxiliary battery commences. An external load can then be taken from the power plant provided that the fuel battery voltage does not fall below 20 V. If this does occur due to a system failure or excessive loading, the external and internal loads are shed and the power plant continues to run on the auxiliary battery. If the voltage falls below 18 V the power plant is shut down. Thus any fault occurring which affects the performance of the fuel battery such as starvation of fuel or air, or loss of electrolyte, will cause the undervoltage protection to operate. An over-temperature protection sheds the external load at an upper pre-set limit of electrolyte temperature or shuts down the power plant under more serious over-temperature conditions.

FIG. 3. Fluid system schematic for hydrazine/air fuel cell power plant.

FIG. 4. 1·5 kW hydrazine/air fuel cell power plant.

The ancillary power requirement of the unit was about 480 W. With a fuel battery which produced an initial gross output of 2·3 kW, the power plant was operated in a test programme for a total of 340 hours. The rated power of 1·5 kW was obtainable within the specification voltage for about 50 hours which included some 20 starts from cold. The performance fell thereafter until after 200 hours the maximum power obtainable was about 1·35 kW gross. From experience with other fuel batteries of similar type this deterioration is most probably due to degradation of the air electrode catalyst bond.

Hydrogen/Air Fuel Cell Systems

The most advanced hydrogen fuel cell produced was a 3 kW pure hydrogen/air power plant developed in the MOD programme by

Energy Conversion Limited. This unit was largely based on the experience gained in the construction of a 2·5 kW breadboard system earlier in the programme. The breadboard system incorporated a 48-cell fuel battery constructed from high performance electrodes, identical for fuel and air electrode, consisting of a 0·15 mm thick porous nickel sheet on which a platinum black/PTFE catalyst mixture was deposited. Using commercially available non-optimised ancillaries this breadboard occupied a volume of 1 m³ and weighed about 200 kg. A similar system was described at the 4th Intersociety Energy Conversion Engineering Conference in 1969[7]. The system was satisfactorily operated at AML for a total of 1270 hours. With the fuel battery initially supplied with the system some 900 hours of operation were achieved with a drop in performance of only 4%.

The development of the 3 kW power plant was designed to follow the electrode technology established in the breadboard system but was required to be capable of operating in the temperature range −5°C to +52°C at specified relative humidities. In addition, target levels of noise emission, start-up time, size and weight were specified. Based on two 34-cell fuel batteries connected in parallel, the system finally constructed differed from the breadboard in two main respects. To obviate the necessity for an inert gas purge the fuel batteries were positioned so that the electrolyte flooded the gas compartments on shutdown and for increased reliability 3-phase ac motors powered by the fuel batteries *via* an inverter were used.

The fluid schematic is shown in Fig. 5. Hydrogen supplied at 70 kN m⁻² and reduced in pressure on the equipment to 3 kN m⁻² was circulated through the fuel batteries. A small constant bleed of hydrogen to remove inerts from the reactant stream was passed to the air scrubber and consumed at the cathode.

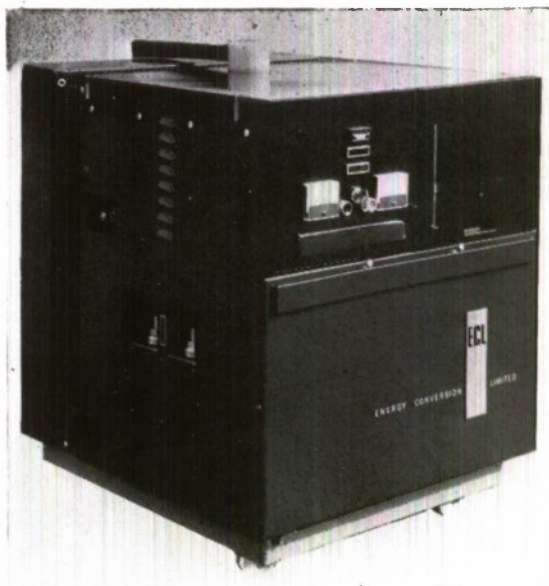

FIG. 6. 3 kW pure hydrogen/air fuel cell power plant.

The air, supplied by a sliding vane pump driven at constant speed, was fed to the batteries in proportion to the fuel cell current by a control valve, the excess being returned to the inlet of the pump. The potassium hydroxide electrolyte was sucked through the
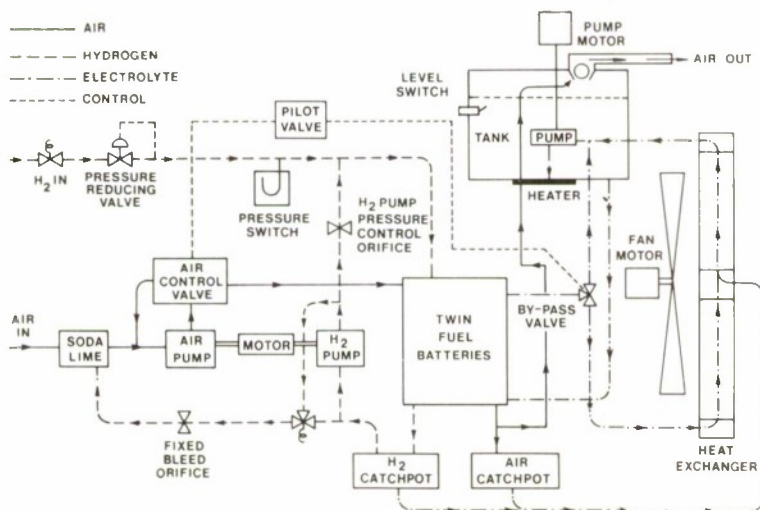

FIG. 5. Fluid system schematic for pure hydrogen/air fuel cell power plant.

fuel batteries by a pump immersed in the electrolyte tank. This pump also returned to the tank at start-up, *via* the catchpots, the electrolyte held in the hydrogen and air cavities during shut-down. Water balance control was accomplished by changing the operating temperature of the fuel cell according to the dilution of the electrolyte, sensed by a level switch in the tank. When the electrolyte had diluted to the high level of the switch the temperature of operation was increased from 65°C to 75°C until removal of water returned the switch to its lower position.

The power plant was fully automatic and safety circuits protected the plant against a number of malfunctions. The equipment is shown in Fig. 6. To reduce fan noise the whole cross-sectional area was used for the heat exchanger with a slow speed, large diameter fan. The heat exchanger occupied more than one-fifth of the total volume, necessary to cater for the $+52°C$ ambient. With dimensions of 660 mm high $\times$ 630 mm wide $\times$ 670 mm long and an operating weight of 295 kg, including soda-lime for 24 hours operation, the specific weight at 3 kW was 98·3 kg kW^{-1} and specific volume, 0·093 m³ kW^{-1}.

The power plant supplied the rated power during 160 hours pre-delivery testing and in the early stages of evaluation at AML[8]. The performance then fell rapidly until after a total of 300 hours the power plant was no longer self-supporting. No specific cause of the deterioration was established but some evidence suggested that it was due to the
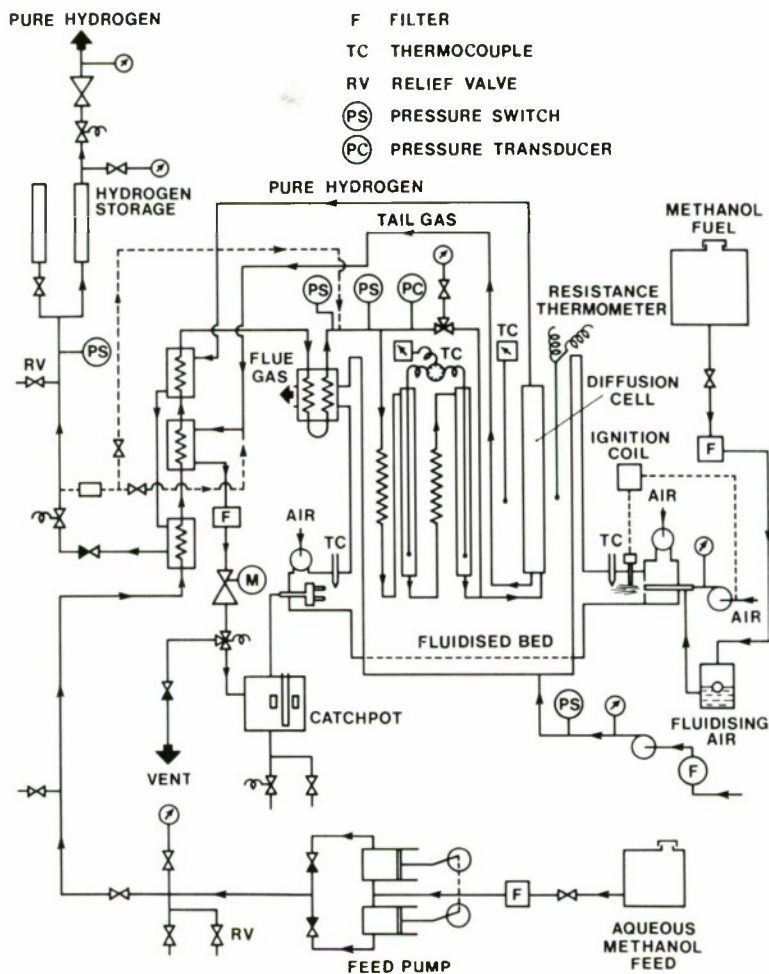

FIG. 7. Flow diagram of methanol fuelled pure hydrogen generator.

flooding of the reactant cavities on shut-down. This was particularly disappointing because in addition to eliminating the need for inert gas storage this mode of operation permitted start-up without reversed cells, a problem usually encountered when the electrodes have been stored in a non-reactive atmosphere. It was not possible in the time scale of the programme to pursue this problem further and the development of pure hydrogen/air systems was terminated at this stage.

Hydrogen Generation

Hydrogen for consumption in fuel cells may be obtained from liquid hydrocarbon or alcohol fuels by various processes. The most efficient of these is steam reforming, where a mixture of the fuel and water is reacted in a catalyst bed to produce an impure hydrogen mixture containing carbon dioxide and carbon monoxide. For use in alkaline electrolyte fuel cells such as has been described above the hydrogen must then be purified. In the early part of the research programme the generation of hydrogen from logistic kerosene and the problems associated with the sulphur content of the fuel, which if not reduced will rapidly poison the reformer catalyst, was investigated. A major complexity identified was the need to free the reformer catalyst from the hydrocarbon/water mixture on shut-down in low temperature environments because of the damaging effect freezing of the water content would have on the catalyst structure.

The system selected for engineering development was a methanol fuelled pure hydrogen generator. In this case the problem of freezing of the feed did not obtain as the freezing point of the methanol/water mixture used was below the $-30°C$ required operating temperature. This equipment was produced under contract by Shell Research Limited. The maximum output of the generator was $1·18$ dm^3 s^{-1} and was designed for operation in association with the 3 kW power plant already described.

A flow diagram of the generator is shown in Fig. 7. Equimolar methanol/water feed is pumped through a series of heat exchangers to six reactors in series (two only illustrated) suspended in a fluidised bed of sand maintained at 335°C. The product gas is fed to a silver/palladium hydrogen diffusion cell also located in the fluidised bed. Pure hydrogen

FIG. 8. Methanol fuelled pure hydrogen generator.

from the diffuser is heat exchanged with feed and passes to a buffer capacity consisting of two $11·5$ dm^3 stainless steel pressure vessels. The hydrogen pressure is then regulated for delivery at 70 kN m^{-2}. The " tail gas " from the diffuser is cooled in a heat exchanger and passes through a motorised valve to a small condensate catchpot fitted with a level sensor which activates a solenoid valve for automatic drainage. The dried gas is fed to a non-aerated burner where it provides heat for the fluidised bed. For start-up energy pure methanol is burned in an aspirating burner supplied with primary air by a small compressor. The burner is ignited by a spark plug. In the start-up sequence feed is supplied when the temperature of the reactor is high enough for reaction to occur. When the reactor pressure reaches about 1 MN m^{-2} tail gas, previously vented to atmosphere, is fed to the burner. As the temperature continues to rise the methanol burner switches off. Thereafter the feed pump maintains reaction pressure between $1·6$ and $1·7$ MN m^{-2} and the tail gas maintains the reactor temperature.

Control of the generator, based on sensing of temperature and pressure, is automatic and over-pressure, over-temperature, overload of the feed pump, flame-out of either burner, sensed by thermocouples and failure of the fluidising air supply produces automatic shutdown. The output of the generator was continuously variable from zero at idling to full output and with the inclusion of the buffer capacity changes of up to 90% of full output could be made with the new demand being met in full while the system adjusted to the new conditions.

The generator is shown in Fig. 8. With the components mounted in a mild steel frame, clad with aluminium alloy sheet, the equipment is $1 \cdot 07$ m high, $0 \cdot 61$ m wide and $0 \cdot 91$ m long and has a dry weight of 233 kg. This volume includes methanol fuel tankage of $4 \cdot 6$ dm^3, sufficient for three starts and feed tankage of 73 dm^3, sufficient for over 12 hours operation at maximum output.

The generator was tested at AML over an operating time of 313 hours including 45 starts from cold and a continuous run of 217 hours[9]. Operation of the system was reliable and except for minor mechanical problems in the early stages, trouble free. The thermal efficiency varied from 45% at $0 \cdot 24$ dm^3 s^{-1} to 79% at full output. The ancillary power requirement in normal running conditions was about 125 W with an additional 75 W during start-up. Little change was observed in the temperature profiles of the catalyst beds, a measure of the catalyst activity, in over 300 hours operation. This together with the results obtained in rig testing of reactor assemblies during the development programme suggest a likely life well towards the target figure of 5000 hours.

Conclusions

The aim of this part of the research programme was to produce, in reasonably compact form, fuel cell and hydrogen generating equipment capable of operating within certain conditions, particularly temperature, which would be imposed by their use in a military environment. This has largely been achieved. That the life of the fuel batteries in the research models has not been of longer duration has been disappointing and this aspect must be the subject of continued investigation.

Acknowledgements

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SUBMARINE CELL CONTAINERS

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From the beginning of the present century until the recent advent of the nuclear submarine, the lead acid cell has been the major source of power for propelling submarines when submerged below periscope depth and even the nuclear submarine has a lead acid battery for emergency use. The requirements of a modern submarine are very different from those in service at the turn of the century. In 1900 the containers in the *Holland* class submarines were made of teak lined with lead and without lids. One can imagine the danger if the submarine went into a dive or motion became turbulent !

The capacity (or power) to weight and volume ratios have increased considerably since those early days as is apparent from Table 1. The containers are now capable of withstanding a level of shock which would have have been disastrous a few years ago. Moreover, their service life, which some 20 years ago was three to four years, is now seven or even more. These improvements have been brought about by better design of the cell and by changes in the material of the container and the lower weight of modern containers has made a significant contribution to the improvement in the capacity to weight ratio. It is not generally realised just how onerous are the requirements for a submarine cell container. The plate group assembly of the cell which weighs approximately 360 kg (800 lb) is supported on the top edge of the container wall which although reinforced to some extent is less than $12 \cdot 5$ mm ($\frac{1}{2}$in.) thick. In addition the container holds 90 litres (20 gallons) or approximately 115 kg (250 lb) of

sulphuric acid electrolyte. When it is remembered that between 112 and 448 cells are fitted in a submarine it will be realised just how dangerous failure of the container would be both to the crew and to the submarine.

Requirements

The requirements which a container has to meet are many but amongst the more important are that it should:

(a) be a good electrical insulator and thermal conductor
(b) be unaffected by acid
(c) not deform or break under shock and vibration.
(d) be durable in use
(e) be light in weight
(f) be non flammable
(g) be readily manufactured.

It is difficult to obtain good thermal conductivity as this is generally incompatible with some of the other requirements. Problems of heat removal therefore do arise but these have been alleviated by improving cells so that the amount of overcharge is reduced and by providing them with water cooling. Good electrical insulation and acid resistance are essential requirements which unfortunately are not inherent in most container and lining materials considered up to the present time. The ability of a container to withstand shock and vibration is undoubtedly the next most important requirement. Shock can be experienced from underwater explosions to depth charging, recoil due to the firing of weapons or in the case of nuclear submarines, to the firing of ballistic missiles.

TABLE 1.

Date	Class of submarine	Type of plate	No. of plates per cell	Capacity in Ampere hours	Weight of cell	No. of cells	Type of container	Approximate capacity to weight ratio
1901	Holland	Rosette	17	1920	910 lb 415 kg	60	Wood lead lined	2·11
1911	Early 'E'	Mercury planté	33	2800	945 lb 430 kg	224	Composition	2·96
1914	Later 'E'	Flat pasted	43	3800 to 4050	885 lb 400 kg	224	Composition	4·29
1927	O, P & R	Ironclad	35	3820	950 lb 430 kg	336	Lorival Ebonite	4·10
1937	S & U	Ironclad	37	4410	970 lb 440 kg	224	Ebonite Neoprene ebonite	4·54
1943	T	Flat pasted	51	5350	960 lb 435 kg	336	Neoprene ebonite Permali wood Bakelite	5·57
1943	S, U & V	Flat pasted	51	5350	960 lb 435 kg	224	Ebonite Neoprene ebonite Permali wood Bakelite	5·57
1944	A	Flat pasted	61	6630	1155 lb 525 kg	224	Permali wood Bakelite Neoprene ebonite	5·90
1950	T conversion	Flat pasted	67	6560	1000 lb 455 kg	448	Permali wood	6·56
1955	A streamline	Flat pasted	81	8000	1200 lb 545 kg	224	Permali wood	6·67
1956	B	Flat pasted	67	7420	1120 lb 510 kg	448	Permali wood	6·62
1960	O	Flat pasted	67	7420	1105 lb 500 kg	448	Glass fibre/resin	6·71
1968		Flat pasted	67	8400	1145 lb 520 kg	126	Glass fibre/resin	7·25

Development

In the early 1920s, containers were generally made of asbestos fibre mixed with some kind of bituminous material as a binder. These were followed in the 1930s by containers produced from a special grade of ebonite. The disadvantages of these containers were that they were brittle and broke easily under shock, and at high temperatures, such as might be experienced in the tropics, they deformed sufficiently to crack. Some containers became porous after a short time in use and porosity was a far more difficult fault to detect than a crack. The plate groups were suspended by bearers from a ledge on the inside of the container (Fig. 1) and not from the cover as in the modern cell. Consequently some weakening of the container was inevitable and manufacturing difficulties resulted in a considerable variation in the container sizes. For many years arguments continued as to whether ledge or lid suspension was preferable without any definite advantage for either approach, but the need to have a rubber lining in containers was eventually considered to be essential and a ledge was not then a practical proposition. Since no other suitable container materials were available at the time, methods of strengthening the existing ones were sought. Initially metal reinforcements were suggested but because there was a distinct possibility of the covering material getting chipped or cracked and consequently of the metal being attacked by acid, this idea was not pursued. Development of the material with a view to making it tougher was therefore carried out and containers were re-designed with strengthening ribs.

In the early years of World War II there was an increasingly urgent requirement for a more substantial and shockproof container. Just how serious the problem was may be gauged by the following extract from a report from one of our submarines of action damage incurred during an air attack. "All main battery containers except 30 in No. 1 Battery and two in No. 2 Battery were badly cracked or smashed. About 150 cells were severely damaged through the bearers for the plate groups being bent". It is interesting to note that the aircraft responsible was a Fairey Swordfish !

Efforts to develop a more shock resistant container were therefore intensified and even the most unlikely materials such as celluloid and polythene were tested. These assumed

FIG. 1. Old Lorival container following shock. Showing bearers for lid.

rather bizarre shapes as a result of the yield test in which the container was filled with water and a weight appropriate to the plate group was suspended from the side and the celluloid container had the appearance of a giant egg timer and was consequently nicknamed " The Mae West ". Few of the materials offered any real promise and the major effort was concentrated on the neoprene ebonite, laminated ebonite, neoprene ebonite reinforced with asbestos and fabricated containers. The laminated ebonite container is shown in Fig. 2. The shock resistance of these containers, with the exception of the neoprene ebonite, was poor and cracking of containers under shock was still sufficiently prevalent for it to be necessary to fit external bags to cells in S, T and U classes of submarine in order to prevent acid leakage. These bags were not very successful, however, as they
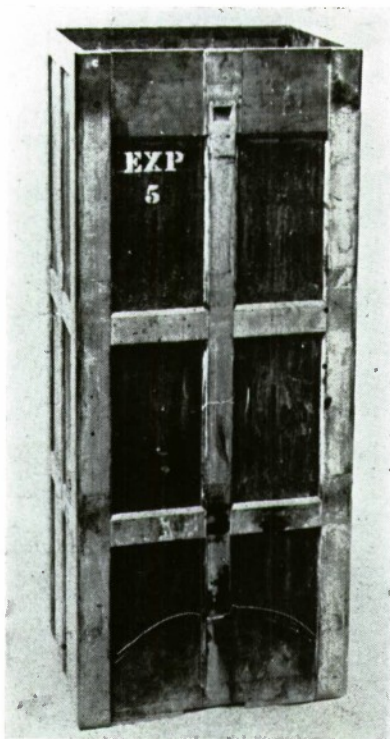
FIG. 2. Laminated ebonite containers. 1942.

FIG. 3. Permali container.

were easily damaged by the sharp edges of broken containers. The neoprene ebonite container although quite good from a shock point of view was too flexible and yielded under load.

The introduction of the fabricated phenolic resin bonded beechwood ply container manufactured by Permali was a major step forward in the development of a shock resistant container (Fig. 3). The four vertical corners of the container walls were constructed with skew comb joints and the base was dovetailed into the bottom edges of the walls. Sections of the underside of the base were cut away to leave four corner pads and a central pad. The container was coated both internally and externally with a chlorinated-rubber based, acid resistant paint. An internal rubber bag was fitted as the container was not acid tight nor was its material acid resistant. The development of a suitable acid resistant rubber was a further problem which required a considerable amount of effort. The combination of the Permali container and lining was a considerable improvement on previous makes and fabricated containers were used in Service from about the end of the war until 1956.
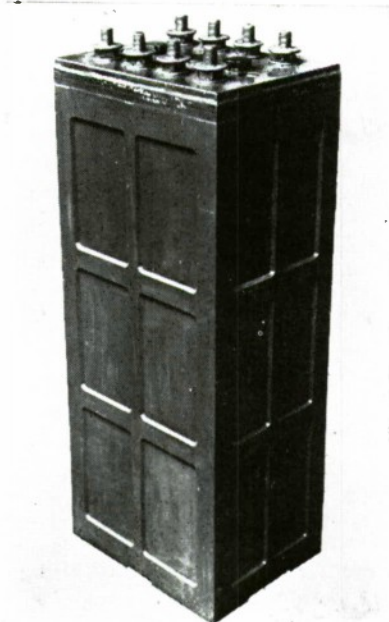
The glass fibre container which was introduced into service in 1956 is far superior to the Permali container. Initially it was actually heavier than the Permali but by re-designing it with thinner walls and strengthening ribs a lighter container was obtained. One disadvantage was its increased cost and like the Permali container it is slowly attacked by acid and therefore an internal rubber bag is still required. The higher cost is offset by the longer service life of this type of container which is now a standard fitting for all British submarine cells and for several of the NATO countries as well.

Up to about 1941 submarine cells were not shock tested but the wall material of the container was subjected to an impact test. The empty container was supported vertically upon a wooden base and a cylindrical weight of about 4 kg (9¼ lb) with a hemispherical end was allowed to fall in an arc from increasing heights on to the side of the container until fracture occurred. This test equipment was replaced by what was in effect the first shock machine. This was rather a crude assembly and is shown in Fig. 4. The container was fitted with a plate group and the appropriate amount of either water or electrolyte and the shock was initiated by dropping a weight of approximately 180 kg (400 lb) through a height of up to 1·6 m (5 ft) on to a striker
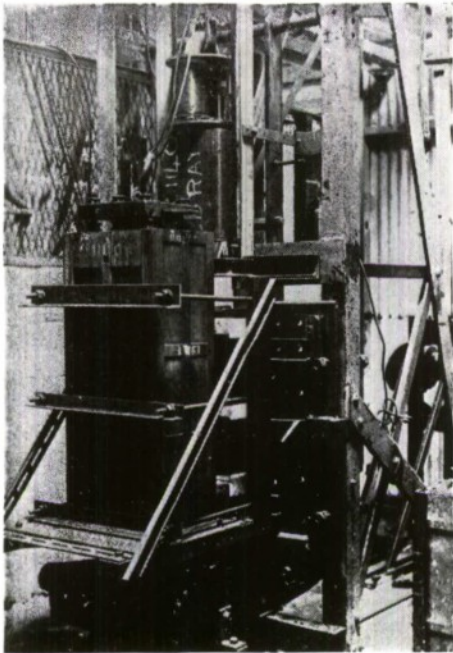
FIG. 4. Early shock machine 1940.

FIG. 5. First upward blow shock machine 1943 - 45.

plate on the framework shown to the rear of the cell in the figure and which is used to retain the cell in position. For lateral blows a similar weight was allowed to drop through an increasing arc up to a maximum of 60° to the vertical. This method did not give very satisfactory results mainly due to uneven tensioning of the springs by which the container was clamped to the machine but improved methods of clamping the container gave much more reproducible results. At this time little information was available on the magnitude of shock which could be withstood satisfactorily by a submarine cell. Non-contact underwater explosion trials were carried out between 1941 and 1946 to simulate the severe shocks likely to be experienced under wartime conditions and much useful information was obtained. For example, it was found that there was a considerable reduction in the shock transmitted to the cells when rubber pads were fitted to the wooden framework on which the main battery was mounted. In addition it was found that the vertical component of shock was the most severe. The existing machine could not provide this level of shock and much work went into the design of a machine which could produce the required level. The first attempt was to drop the cell vertically using guides but the difficulty was that the cell did

not fall true. Bottom blow testing, which was believed to be more typical of the type of shock received by cells, was then investigated and an upward blow machine which could produce the required level of shock was developed. Essentially it consists of a steel plate on which the cell is mounted vertically, the plate being bolted to a steel structure which is rigidly embedded in concrete. A hammer of approximately 450 kg (1000 lb) swings from various degrees of arc in a vertical plane and strikes a steel plate underneath the cell. The blow is transmitted to the test plate by means of compressed helical springs which enable the acceleration to be controlled, Fig. 5. This machine was used considerably in the latter part of the war and went into operation on the basis of a known calibration in 1945. This machine is now being superseded by a two tonne shock machine which can impart the more severe level of shock which is required to test present day equipment (Fig. 6).

Improvements

Although the shock resistance of the container is of paramount importance, because of the limited space available in the battery compartment so too are its external physical dimensions. Therefore any improvement in cell performance has to be achieved either by increasing the internal dimensions of the container *i.e.* by making a thinner wall, or by the use

FIG. 6. Cell mounted for test on 2 tonne machine.

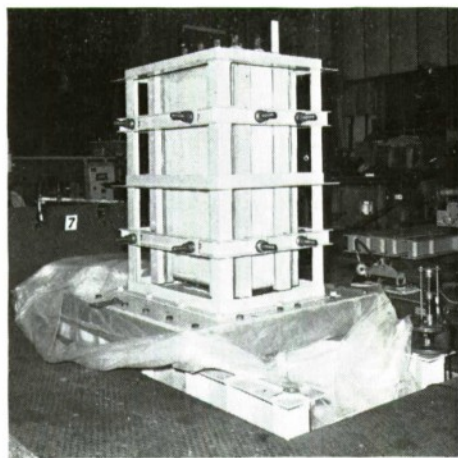of a lighter material although the former may have the disadvantage of reducing its resistance to shock. Little information is available about the early containers but the average weight of the Type 5350 neoprene ebonite container was between 30 kg (66 lb) and 33 kg (73 lb). It had of necessity very thick walls, 16 mm ($\frac{5}{8}$ in.) to provide the required shock resistance. The resin bonded beechwood container developed by Permali provided a much better shock resistance with a wall thickness of 13 mm ($\frac{1}{2}$ in.). The Type 6560 in this material weighed 30 kg (66 lb) but because of its poor acid resistance an internal rubber lining weighing 6·3 kg (14 lb) was fitted; so nullifying any saving in weight. An improvement in shock resistance was obtained with the glass fibre container which has a wall thickness of about 6 mm ($\frac{1}{4}$ in.). The Type 7420 glass fibre container weighs 25·5 kg (56 lb) compared with 32·2 kg (71 lb) for the Permali beechwood container. This with a thinner wall of the glass fibre type a larger volume of electrolyte is available and the capacity to weight ratio has been improved from 6·6 to 6·7, an increase of approximately 1·5%. Far more impressive are the figures relating to the Type 7420 and Type 8400 cell. The Type 8400 cell was developed primarily to provide the increased power required by nuclear submarines without any increase in external dimensions of container. By reducing the wall thickness and by internal shaping a barrel container has been developed which gives this cell a 10% increase of available electrolyte over the Type 7420 cell. The weight of the barrel container is

20 kg (44 lb). The greater volume of electrolyte of a somewhat higher specific gravity has resulted in an improved capacity to weight ratio of 7·25, approximately 8% higher than that available from the standard Type 7420 cell.

Manufacture

The manufacture of glass fibre containers is a slow and messy job. Fortunately the equipment is relatively simple and cheap and the polyester resins which are used can be cured at low temperatures without pressure. A brief outline of the process is as follows. A metal former whose external dimensions are the internal dimensions of the finished container is first coated with a silicone grease which enables the container to be more easily withdrawn in the final stages of the process. A resin is liberally pasted on to the former and the first layer of glass fibre matting, taller than the former, is wrapped round. The glass matting extending above the top of the former is slit vertically in several places and the strips so formed are laid over the top. A piece of matting of slightly larger dimensions than the end section of the former is pasted with resin and stuck over the top of the strips. This thin skin of glass fibre forms the shell of the container. Further coatings of resin followed by further wraps round of glass fibre matting are added until the requisite number of layers have been applied. Extra vertical strips are applied to the corners and to the centre of the sides to form the ribs and strips are also added to reinforce the base. Separate metal platens of the required shape are then placed against the four sides and the top, which becomes the base, and pressure is applied to remove the excess resin. The amount of resin required for the process is roughly 70% of the dried weight of the container. The whole assembly is then placed in an oven and cured for approximately 2½ hours at 150°F. When the curing is completed the assembly is removed from the oven and cold water is passed through the former to cool it at the required rate. The platens are then removed and the pressure on the inside of the container is equalised by drilling small holes near the base. The container is then withdrawn from the mold. The drilled holes are subsequently used as drain holes for acid in the event of a leaky lining and enable leaking to be readily detected at the factory. These holes are now filled prior to the container going into service.

Future

What of future development of new and stronger materials for container manufacture or for making existing containers lighter by some novel change in design? It is possible that the walls of the glass fibre container could be made thinner but stronger by using different weaves of glass cloth. However, a stronger type of glass cloth would almost certainly have an increased glass content with a consequent increase in container weight. Thus any weight advantage may be marginal.

Shock and vibration tests have been carried out satisfactorily on small A.B.S. (acrylonitrile butadiene styrene) containers although not to the same high level of shock as for submarine cell containers. The results were encouraging and high impact A.B.S. has the advantage of having a specific gravity of between $1 \cdot 0$ and $1 \cdot 1$ compared with approximately $1 \cdot 5$ for the present glass fibre material. Whether A.B.S. could be molded into a submarine container size only time and engineering experience will tell. Deformation at high temperature and under load could occur resulting in another Mae West container.

A substantial saving in weight by the use of a thinner wall is offered by using carbon fibres in place of glass. However, the present cost of carbon fibre is prohibitive and the price of a container made from this material would probably be about 20 times that of the glass fibre resin type which costs approximately £50. It must be remembered too that as carbon is a conductor special precautions would have to be taken regarding insulation problems. A compromise could be the use of a sandwich construction of glass fibre and carbon fibre. Even this type of construction would be very costly and its future use for submarine container manufacture must be based on carbon fibre production costs falling appreciably during the next few years.

The weakest point at the present time is the cover and effort is being concentrated on making this stronger. A re-design to make a neater top is being considered together with the use of new materials, *e.g.* polypropylene, either alone or as a coating to the glass fibre lid.

THE THIRD INTERNATIONAL CONGRESS OF THE INTERNATIONAL RADIATION PROTECTION ASSOCIATION

Reported by J. R. A. Lakey, B.Sc., Ph.D., F. Inst.P.

Royal Naval College, Greenwich

Over 850 health physicists representing 22 associate societies attended this Congress which is held every three years to review the whole field of radiation protection. The Congress involved the presentation of 230 technical papers, mainly by rapporteur session, a technical exhibition, a General Assembly and culminated in visits to nearby nuclear facilities. The Congress was the first occasion at which the Radiation Hygiene Section of the Scientific Society of Hygienists of the USSR had attended as members of IRPA. At the General Assembly, Carlo Polvani of Italy was elected President and it was agreed that the next Congress would be held in Czecho-slovakia on 5th - 10th September 1976 prob-ably in Prague. The IRPA is now recognised by the World Health Organisation and, if funds permit, will continue to support the International Commission on Radiological Protection. The UK is represented on the Executive Committee by Mr. Brian Lister (UKAEA).

The proceedings of the Congress are to be published by the USAEC in two volumes through the National Technical Information Service, Springfield, Virginia 22151, USA probably in March 1974.

Radiation Perspectives in the USA

This session revealed the present USA pre-occupation with consumer pressure groups and gave the floor to Ralph Nader (Managing Trustee of the Center for Study of Responsive Law) and to the Hon. Melvin Price, Chairman of the Joint Committee on Atomic Energy (JCAE). Nader's allegations that AEC were suppressing nuclear safety information was refuted by the third guest speaker, Ralph E. Lapp (Consultant) who referred to AEC pub-lications* and suggested that the USA was in danger of setting a double standard for radia-tion risks—one for power, the other for the dominant risk to the population, medical diag-nosis. He supported the "as low as practic-able " standard of the AEC but felt that the diagnostic use of X-rays required better con-trol.

Melvin Price reviewed the JCAE work leading up to the USAEC's well known 5 mrem/year proposal and said the final version of the rules for " Environmental impact statements " would soon go before his com-mittee.

Radiation and Man

The theme of this session was a discussion of the USA National Academy of Science Report on the Biological Effects of Radiation (BEIR report). The comments compared the BEIR report with the United Nations UNSCEAR report. Papers by J. F. Crow (University of Wisconsin) and A. C. Upton (University of New York at Stoney Brook) dealt with the uncertainties and bases for the BEIR comments on Genetic and Somatic Effects respectively. Dr. Comar presented a review of the BEIR report and stressed that

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* Safety of Nuclear Power Reactors and Related Facilities AEC - WASH 1250 (1973).

radiation protection standards should not be set arbitrarily against the natural background but rather should be established in terms of the minimal exposures required to fill societies' needs. This cost benefit approach would have to be applied to other environmental pollutants since the time was coming when priority decisions would have to be made in the allocation of limited resources for the maintenance and improvement in the quality of life. The BEIR report makes use of a linear relationship between effects at the lowest accurate point of measurement and that at zero dose and, although this is a plausible assumption for some effects, the model may yield over-estimates because of the failure to allow for possible repair of injury from low LET radiation at low dose and low dose rate.

Comments on the presentation reflected the over-riding concern for the risks of medical diagnosis but Professor Spiers reminded the Congress that the medical application was an individual event and carried out for the immediate benefit of that individual. Dr. Sowby of the ICRP, pointed out that it is usually impossible to achieve an average dose rate in any population group equal to the limit for that group—for example the 170 mrem/year derived from ICRP recommendations could never be the average dose received by a population as used in the BEIR report. He felt that $0 \cdot 05$ rem per year (*i.e.* 1/10th of the ICRP recommendation) was more realistic for the public and represented a risk around 5×10^{-6} per year which was near to levels accepted by society for transportation.

Turning to non-ionising radiation Dr. Michael J. Suess (WHO Regional Officer for Europe) reported WHO plans based on the recommendation of the Working Group convened in 1971. A model code of good practice is to be prepared and should be ready for a second Working Group in 1975. Progress in the reduction of microwave leakage from ovens was reported from the Texas State Department of Health and showed that general standards of sanitation and maintenance correlated closely with leakage levels in the food vending facilities surveyed.

The ' As Low As Practicable ' Philosophy

Continuing in the rather parochial style of the Congress, Mr. M. Goldman discussed the ' public relations exercise ' of AEC in demanding exceptional low doses (5 mrem/year) at the site boundary of operating reactors. He ridiculed the concept of the ' maximum man ' who was assumed to eat fish caught in the effluent at twice the amount consumed by commercial fishermen and to sit naked all the year round on the site fence post next to the cow which produced the milk he consumed. AEC had retained this concept in the July 1973 statements on its rule making procedures for reactor siting. Mr. Goldman's thesis was that the USA may have to face an increase in the real exposure (to operating staff) to obtain a decrease in the hypothetical dose received by the ' maximum man '. He cited the case in which five man rem were consumed in a resin change of a Pressurised Water Reactor by the operating crew to achieve a reduction in effluent levels which were of no practical concern. Whilst Mr. Goldman may have exaggerated in presenting his point of view he made a convincing case to suggest that the AEC had over-reacted to a small but vocal group of the population! There was some debate about the dose cost of nuclear power generation: the UNSCEAR report calculated two to three man rem/MW year; this could be exceeded in the USA because of the high occupational dose. Dr. K. Z. Morgan disagreed with Mr. Goldman and stated that when environmenal levels are reduced there is frequently a reduction in the dose of the operating staff and he suggested that AEC's problems originated in the failure to employ qualified health physicists on nuclear power reactor stations.

Radiation Quantities and Units

The Chairman of ICRU, Mr. H. O. Wyckoff, discussed two views on the concept of Dose Equivalent:

(a) A unit of risk and therefore dimensionless

and

(b) A weighted value of absorbed dose or a reference value of dose giving the same effect and therefore having units of rads.

In practice the ICRU recommends that the ' rem ' be retained for dose equivalent. Although the use of this unit is redundant from both the above points of view it helps to ensure safety and is therefore to be retained.

Dr. Harold H. Rossi (College of Physicians and Surgeons of Columbia University) and a member of ICRU supported the concept that it is useful to name quantities in the interest

of communication. He referred to the last report of ICRU (Report No. 19, 1971) which defined Absorbed Dose Index (D_1) and Dose Equivalent Index (H_1) in a 30 cm diameter sphere of tissue equivalent material. This quantity is closer to the absorbed dose in a man than any theoretical quantity such as 'tissue kerma in free air' and yet can be rigorously defined and calculated. A plea came from Mr. A. Allisy of the Bureau International des Poids et Mesures to introduce the SI units as quickly as possible with the rejection of rads, roentgens, rems and curies. He professed the ease of communication achieved by a common language of units but failed to convince a sceptical audience. Jacob Neufeld (Oak Ridge) further discussed the rem and in particular suggested that the Quality Factor *versus* LET relationship could be further refined by expressing biological data on animals in a set of linear equations which could be combined with data observed on men. It was generally agreed that quantities such as the RBE represent value judgements and cannot be made more accurate by using mathematical expressions to correlate the sparse data.

Radio-Ecology

This session included a number of interesting papers especially a report by T. F. McCraw (Division of Operational Safety, USAEC) who described the repatriation of the Bikini Atoll and reported residual activity being mainly due to Caesium-137 and Cobalt-60. M. E. Wrenn (Institute of Environmental Medicine, New York University) discussed sediment interactions of Caesium-137 and 134 in the Hudson River following discharges from the Indian Point nuclear power station. Spatial dependence of the activity in sediment depended on local scouring and depositional features but the longitudinal distribution in river water followed expected hydrodynamic transport models. John Mauro from the same establishment claimed that there was an absence of a trophic level effect for Caesium-137 in the estuary although the presentation did not offer conclusive evidence of this effect.

Reactor Experiences, Waste Management and Environmental Monitoring

Atomic Electric Power Stations as sources of Carbon-14 were analysed in a report from the Biophysics Institute of the USSR Health Ministry. A simple model was evolved to predict C^{14} release rates for graphite and water

reactor systems and this was used to predict the global releases at the year 2010. This would be about 10^4 curies per day leading to a concentration 10 times the present natural level. The genetic consequences of this contamination may necessitate control of C^{14} releases in due course.

Dr. N. T. Mitchell of the UK Ministry of Agriculture, Fisheries and Food stated the case for the pragmatic approach of the UK to radioactive waste disposal. The aim is to put neither the environment nor the public at risk and as far as possible not to make excessive economic demands. Together with co-author M. M. Wasson he also reported specific experience at Bradwell Power Station where Zinc-65 and Silver-110m have been the predominant components in terms of their environmental significance. Effective methods of removing zinc and continuous vigilance on changes in effluent composition have held the public radiation exposure to a small fraction of 1% of ICRP recommendations.

The rapporteur, Mr. R. Wilson of Canada considered the above papers to be the more important but was also interested in the "policy statement" by Mr. F. Passant of CEGB Cheltenham who stated the following activity release criteria:—

1. Food and air contamination levels not to exceed 0·05 dwl averaged over one year.
2. Maximum release rate not to exceed four times the level corresponding to the above.
3. External doses to be added to doses due to waste discharges and total dose not to exceed 0·1 rem/yr assuming 100% occupancy.

Predicted releases were compared with figures derived from CEGB and ICRP criteria and the total dose expected to be 43 mrem.

F. Morley of the NRPB, UK, reported on a mathematical model to evaluate surface water concentrations of radioactivity as a result of deep ocean dumping. The model showed that the effect of uncertainties in the diffusion parameters is of no importance for nuclides with long half-lives. This type of model work is essential for rational decision making and is complementary to the operational procedures described by Dr. Mitchell.

Turning to atmospheric dispersion some useful experimental data from an operating BWR was described by L. Battist using an ingenious new field survey monitor capable of

measuring down to 10^{-9} μ Ci/cm³. Values of X/Q (the meteorological dispersion) were found to range from 10^{-9} sec/m³ to 10^{-4} sec/m³. This data being specific to the site could be used to generate micrometeorological factors for local site dosimetry. Longer range predictions extending beyond 100 kilometers were examined by P. Cagnetti of the Italian National Committee for Nuclear Energy. The particular application under consideration was the dosimetry of Krypton-85 but the values quoted are likely to be true only for short period releases and were seen to be conservative values when applied to the Windscale Accident measurements (values 10 to 100 times higher).

Dr. Wheatley of BNL described research activities at BNL of the CEGB. Fundamental work was in progress on such topics as skin thickness, skin doses, and tissue volume over which averaging is permitted. Such work allows the CEGB a full understanding of the problems and allows the board to express its own soundly based opinions and so influence the operating conditions specified for its stations. Applied research is concerned with fission product inventory and the consequences of continuous and accidental releases to the environment. Operational research is concerned mainly with monitoring techniques and equipment and the advantage of the Board having its own calibration service was stressed.

Mr. Goldfinch, also of CEGB, presented a summary of seven years experience at Dungeness "A" station from commissioning to normal operation. Station doses are low *i.e.* less than 100 man rem/yr, with an average dose for occupational workers of less than 0·3 rem/yr in 1972. At Dungeness, neutron doserates are significant, mainly due to intermediate energy neutrons as estimated by multiplying slow neutron dose from film badges by a factor of about 5.

Atmospheric releases from the station have led to no increased activity in milk and herbage in the area. The main discharge to atmosphere is A^{41} (about 500 Ci/day per reactor) with small amounts of Ag^{110m}.

The liquid discharges are:

H^3—initially about 600 Ci/yr, now about 20 Ci/yr.

All other isotopes—170 Ci/yr at maximum but now only a few tens of Ci/yr—principal isotopes are Cs^{137}, S^{35}, Cs^{134} and Sr^{90}/Y^{90} in descending order.

Mr. Wasson of CEGB Bradwell, described the principal sources of liquid waste at Bradwell, N.P.S. These were cooling ponds and gas driers with H^3, S^{35}, Zn^{65}, Ag^{110m} and $Cs^{134, 137}$ as main activities. Radiologically S^{35} was most significant initially but now Cs^{137} has become so with higher fuel burn-up.

Improvements in effluent treatment processes have considerably reduced discharges of liquid activity. Of the released activity Zn^{65} was the critical one initially but Ag^{110m} has now taken over the leading role. This is derived from silver nitrate used to mark identifications on fuel elements. Discharge figures for 1963 - 72 show that Zn^{65} discharge was a maximum in 1967 and Ag^{110m} discharge a maximum in 1971.

Doses resulting from the consumption of "critical pathway" foods are very much below the ICRP limits.

In a paper by E. Nagel of EIR Switzerland the special problems caused by unusual air movements associated with local topographical factors in Switzerland were discussed, with regard to predicting the effects of releases of radioactivity to the atmosphere.

Mr. Konig of Karlsruhe, Germany reported figures of the release of H^3 from two heavy water reactors and one reprocessing plant. A total of about 4000 Ci/yr of H^3 is released to atmosphere and to the Rhine. A comprehensive monitoring programme, using liquid scintillation counters, is carried out to measure H^3 in surface and drinking waters.

In future some high level H^3 waste will be disposed of in a disused oil well instead of to the Rhine. At present doses to the public from these releases are negligible.

Personnel Dosimeters

The continuing evolution of thermoluminescent dosimetry (TLD) and its take over of the role of the film badge was revealed in this session which had six papers on TLD to one on film badges. The British National Radiation Protection Board described a TLD badge compatible with automatic processing which could use disc or extruded forms of TL materials which was likely to be used for 10^6 readings per year and should have a precision of 10 millirem up to a dose of 50 millirem. Similar automatic facilities were described by the Netherlands Radiological Service Unit TNO who anticipate the use of TLD for 9000 radiation workers on a bi-weekly basis. Development at the Danish Atomic Energy Com-

mission appears to be less advanced than these first two systems but the choice of a hot nitrogen gas heating method and the inclusion of a neutron dose estimation component is interesting. Klaus Becker of Oak Ridge National Laboratory described attempts to use TLD to replace film for fast neutron dosimetry. His method uses high melting stable organic compounds to provide the recoil proton capability without impairing readout.

Dale E. Hankins (Los Alamos Scientific Laboratory) reviewed progress in personnel neutron dosimetry and particularly in the use of albedo systems. These have rather poor energy dependence which reduces their accuracy. Fission fragment methods were also discussed in detail with only brief reference to TLD methods.

The Sievert Lecture on Radiation and Man

The first recipient of the Rolf Sievert award is Professor Bo Lindell, Director of the Swedish National Institute of Radiation Protection. The lecture delivered by Professor Lindell on the occasion of the award was entitled "Radiation and Man" and was a development of his cost benefit analysis in radiation protection decision making in which he postulated a dollar equivalent of the rad. Taking $100 for this quantity he showed that present probability data would make it worth spending $1 million to save a human life although the reverse is not true—dollars and human lives are not exchangeable quantities. This dollar value of the rad could be applied to medical doses: for example the dose delivered in female urography equates to $60 this sum is therefore worth spending to reduce the dose ! He developed this argument through a discussion of natural radiation doses — why accept these without taking countermeasures ? —to the cost of the nuclear power programme which looked small compared to the cost of bomb testing. This paper gave a stimulus to attempts to put radiation hazards in perpective—compared to other "hazards of living" mankind responds to the possibility of risk from radiation when many other hazards are ignored so long as they cannot be measured !

Dose Calculations

The dosimetric aspects of the forthcoming report of ICRP Committee 2 on internal emitters was announced by Dr. W. S. Snyder (Oak Ridge National Laboratory). The limits for the intake of radioactive materials will

be framed in terms of the maximum permissible annual doses recommended by the Commission. Thus the basic standard will be the Maximum Permissible Annual Intake (MPAI) which is the intake which will deliver the Maximum Permissible Annual Dose to the critical tissue.

The only derived limit which will be quoted in the report is to be the Derived Air Concentration which is equivalent to the MPAI if the standard man inhales air for 2000 hours (*i.e.* 50 weeks at 40 hours per week) at this concentration. There is no equivalent derived water concentration since radiation workers are not normally exposed to contaminated water supplies. The old quantities of Maximum Permissible Body Burden (MPBB) and Maximum Permissible Concentrations (MPC) will not appear in this new report.

A number of papers from Oak Ridge gave improved data on specific effective energies and specific absorbed dose fraction, the latter quantity being quoted as a function of age. It is worth commenting on the errors inherent in these factors — two authors quoted variations in dose up to a factor 2. L. N. Smirenny (Institute of Biomedical Problems, Moscow) reported the use of a "dose-equated man phantom" and illustrated its use on board the automatic interplanatory station "Zond-7".

External dose calculations covered a wide range of source energies but a particularly useful presentation by J. M. Wyckoff (National Bureau of Standards) gave the dose equivalent rate behind concrete walls up to 800 gram/cm^2 initiated by accelerator produced neutrons up to 100 MeV. The data was condensed into an empirical expression with suitable constants for more than 60 selected examples of neutron production reactions. R. Schneffer (Electricite de France) showed that the ICRP recommended values for the MPC in air for inert gases are conservative particularly in the case of Krypton and Zenon although the values used for Argon 41 could not be increased further.

Operational Health Physics

The problems of decommissioning a power reactor were revealed by D. McConnon of United Power Associates, USA in a very interesting paper describing the dismantling of a 58 MW(Th), 22·5 MW(E) BWR at Elk River. The reactor was critical in 1962, on power in 1964 and shutdown in 1968 for

economic reasons. Fuel was removed in 1968/9. Dismantling of reactor structure started in 1972 and is expected to take $2\frac{1}{2}$ years. The reactor internals were removed first and these have been disposed of and the biological shielding is now being removed.

The total long-lived activity was about 10,000 Ci with contact doserates up to 8000 R/hr. Remote and under-water methods of dismantling were used and large components reduced in size by mechanical methods or by "burning". The waste was loaded into disposable containers and transported to a burial ground. Dose-rates during transport operations were up to 2 R/hr and usually below 200 mR/hr.

Most dose to the dismantling team was due to long periods being spent in fairly low dose-rates. Of the total of 80 people, 11 were health physics personnel. A total of 62 man rem was received by 82 people with a maximum dose of 4·8 rem. The outstanding dose was estimated at 20 - 30 rem. Whole body counts were carried out and Cs^{137} and Co^{60} found but always at less than 1% of the MPBB. Doses to the public from dismantling were estimated to be 0·4 mrem. The total cost of dismantling was estimated at $5·2 million but no special "hazard payments" were made. The importance of proper advance planning and rehearsal was stressed, so as to minimise exposure times, and the importance of the ultimate dismantling of a reactor should be given full consideration in the design stage.

Exposure from Nuclear Power

The theme of "as low as practicable" was continued by G. Hoyt Whipple (University of Michigan) who recalled that the phrase had been introduced by ICRP but was now elevated to a regulatory standard by the USA AEC—following Goldman's earlier remarks he queried the logic of a philosophy which declares that if it can be done it must be done. In practice effluents from US Power Stations have shown a decreasing trend for gaseous and halogen effluents but, Andrew P. Hull (Brookhaven National Laboratory) reported an increasing trend for liquid tritium effluents.

Similar reports on the low level of actual releases from nuclear power reactors were made by G. A. Gunizakov (USSR Ministry of Power and Electric Power Stations) which quoted population doses not exceeding 1·5%

of the natural background at three USSR reactor sites. The use of "man rads" as a parameter was queried in discussion—authors do not always define the scope of their calculation—does the dose include occupational exposures? Is it a global calculation? These questions developed a discussion on the nature and style required in communicating the above data to the public. The scientific mode is not acceptable to the mass media— it was suggested that the public were not afraid of dying *per se* but were afraid of dying in some mysterious new way. Mr. M. Delphia (Electricite de France) asked that nuclear plants be set free from this emotional load and data should be related more to "individual risk" rather than "collective damage".

Non-Ionising Radiation

A survey of the protection problems involving non-ionising radiation was made by H. Jammet (CEN France). The radiation involved was mainly Electromagnetic—including micro-wave (ovens etc.) and lasers (from toys to medical applications), ultraviolet, long infra-red. The action on biological systems was mainly due to thermal effects but there could be some electric and mechanical interactions as well. Lasers were the most obvious hazard particularly to the eye where damage to the retina could be permanent and some regulations did exist but there was no equivalent to the ICRP in this field. There was also a generally agreed limit of 10 milliwatts/cm² for microwaves and, in this context, the emission levels from the domestic oven was not negligible. The World Health Organisation had issued recommendations on ultra-violet light; a limit of 0·5 microwatts/cm² for exposure periods not exceeding seven hours had been set but there was no reliable data to settle the question of a threshold dose for this radiation.

Public Information, Legal Aspects, Education and Training

Two papers were presented on training covering technician training courses in Switzerland described by H. Brunner (School for Radiation Protection, Wurenlingen) and the philosophy and practice recommended for the project training of graduate students in health physics by J. R. A. Lakey (RNC, Greenwich). Discussion on these papers included brief

reports on other courses and revealed the expected wide variations in standards and the need for agreed qualifications. (The Certification procedure of the American Board of Health Physics being the only scheme in existence).

Charles F. Eason (Office of the General Manager, AEC) discussed the law and cases involving low level radiation exposure and stated that adjudication in the USA on these cases had all the attributes of a lottery. The concept of aggravation had been used on several occasions in the USA when low level occupational exposure after earlier therapeutic exposure had been deemed to contribute to leukaemia and the claimant won his case against the employer. His suggestion for improving the situation would create in the USA a situation similar to the UK National Insurance but some speakers thought it would be better to assume any worker coming down with a disease which could have been caused by radiation should be compensated automatically.

Public information and confidence was reported to be in good shape in the United Kingdom by Dr. J. A. Bonnell (Central Electricity Generating Board, UK). The British public have been treated like rational and intelligent human beings and have behaved that way. Rather than undermining public confidence the Windscale experience appears to have reassured the public that the authorities can act wisely and quickly in the case of a reactor accident. On the other hand W. Koelzer (Karlsruhe Nuclear Research Centre, FRG) believes that some of the USA controversy has been imported to his country resulting in action groups and intervention of the mass media which misunderstood the facts of the case. The discussion of these papers stressed that reactor users should not use " Public Relations " to promote their activities but should pay attention to " Public Information ".

Science Writers Evaluation of the Congress

The unusual step of inviting science writers to present their evaluation of the Congress produced an entertaining statement from Frank Carey (Washington Bureau, Associated Press) who initially declared his bewilderment with the technicalities of radiation protection and admitted that controversy makes news especially when it surges round one's own health and safety. News has to compete with other happenings and some human interest has to be present in a story if it is to be published. He then listed 14 items of the Congress that had caught his attention and his parting advice to scientists when talking to the public was " to choose your words as if you had never heard of a pico-curie, *maybe even the word is radioactive* ".

Another newsman, Henry T. Simmonds (Newsweek) agreed with earlier comments that the British Public was relaxed about radiation hazards but was sceptical about any credit being given to National policies. He found it hard to write news stories about human risks in absolute terms but preferred to use relative quantities—for example the enormous number of road deaths per year in the USA seems to be a tolerable quantity because the public keep putting up with it year after year.

Conclusions

In a conference of the size mounted by IRPA it is difficult to avoid a miscellany of papers on a wide range of subjects. The USA organising committee avoided this impression by choosing lead speakers to highlight the present environmental dilemma in the USA. This inevitably brought a parochial air to some of the proceedings but the painful lessons being learned in the USA should be examined with great care by any nation with a developing nuclear power programme. The UK was frequently used as a model of excellence in the field of public relations but for example, W. Germany had already detected the spread of the USA hysteria to its own country so that immunity cannot be guaranteed.

The Congress successfully provided a forum for world wide interests and was well worth while.

Acknowledgements

ROYAL NAVY OPENS

UNIQUE RESEARCH

LABORATORY

J. R. Elgie, M.I.Nuc.E., A.M.I.Env.Sc., R.N.S.S.

Institute of Naval Medicine

Introduction. On 1st May 1912 the Royal Naval Medical School was opened at Greenwich College by Admiral Prince Louis of Battenberg, then First Sea Lord, in the presence of the Medical Director General of the Navy, Sir James Porter and representatives of the Services and of the medical profession. In his speech, Prince Louis congratulated the newly entered naval surgeons who represented the first course and said that it was most necessary to the efficiency of the Naval Service as a whole that they should avail themselves fully of the medical advantages now afforded by the school.

The School, which was opened with such a flourish, owed its inception to the recommendations of the Durnford Committee, one of those bodies which, from time to time, have been called upon to inquire into the conditions of service of medical officers and to suggest steps for improvement. Among the specific terms of reference of this particular committee was an inquiry into the arrangements for post-graduate education of medical officers.

Previous courses of instruction for newly entered Medical Officers were first started at Haslar Hospital in 1880. Instruction continued here for many years under rather crowded conditions, with general and naval hygiene, hospital work, physical training and dentistry forming the main subjects of the syllabus. During these years the new specialities of tropical medicine, bacteriology, clinical pathology, skiagraphy (radiography) and anaesthetics were added gradually. In 1889 the course was extended to four months and lectures and instruction on diseases met with on foreign stations were first introduced. Corresponding arrangements had first been made in 1889 for other Medical Officers during their Service careers to undergo a post-graduate course of three months duration at a London Teaching Hospital every eight years.

The Durnford Committee considered these matters at length and recommended that a Naval Medical School be founded at R.N. College, Greenwich in order to co-ordinate the various aspects of post graduate training of Medical Officers. The Committee believed that such a school would add considerably to the prestige and reputation of the Service, and that the opportunities for scientific research would be encouraged.

The Medical School which started in this way thus became the centre responsible for the correlation of post graduate instruction and was recognised by the London University as a School of that University.

The association with the R.N. College, Greenwich continued until the outbreak of war in 1939 when the Naval Medical School was uprooted and eventually came to rest in a private house at Clevedon, Somerset. In 1943 when the benefit of penicillin became apparent, and when the supply of the substance became difficult, arrangements were made to produce it at the Naval Medical School. Large quantities of penicillin were produced before this activity was discontinued in 1946, by which time commercial firms were producing cheaper penicillin and it was no longer necessary, reasonable or economical for the Navy to manufacture its own supply.

The activities of the Naval Medical School were also becoming very much concerned with preventive medicine and bacteriology. Preventive medicine in those early days meant the control and prevention of communicable disease though now it is regarded in a broader sense as helping the individual to attain optimum health, efficiency and well-being.

Following the war years of 1939 - 45 the Royal Naval Medical School was moved in 1948 to an old Georgian mansion in Alverstoke, Gosport, Hants and in April 1969 was renamed the Institute of Naval Medicine.

Civilian medical graduates, doctors from the other Armed Services and allied navies, health physicists and naval technicians attend courses, seminars and symposia organised by the INM: closest academic links exist between the Institute and civilian hospital research units, university medical departments and the Royal Navy Physiological Laboratory. Applied research is conducted in collaboration with a committee of the Medical Research Council (the R.N. Personnel Research Committee). It has thus continued to grow in size and accomplishment.

Environmental Medicine Unit

An important new medical research facility was brought into operation in November 1973 at the Institute of Naval Medicine, called the " Environmental Medicine Unit " (EMU). The new £200,000 complex makes possible for the first time the detailed and accurate measurement of the effect on man of various long-term environmental situations. For example,

factors affecting life in submarines on long patrols can be reproduced, measured and studied. Many other situations, climatic and otherwise, affecting servicemen and their jobs can be simulated.

Focal point of the new unit is a chamber which, as a permanent installation of its size, is unique. Some 12,000 cubic feet in volume (the size of a modern flat), it can support up to 12 men in continuous isolation for long periods. Integral with it are sleeping facilities, a kitchen and a toilet area with two showers. The main floor space can be divided into working and recreational areas.

Access to the chamber is through an air lock and there are airtight observation windows. Inside, the atmosphere which the occupants breathe can be controlled to very precise limits. Atmosphere contaminants or additional gases can be fed into the closed circuit air system. Temperature, humidity and airflow can be varied to create a wide range of climatic conditions. Associated mechanical plant, a control room incorporating data-recording systems, laboratories, offices and workshops complete the unit complex.

Designed to meet the Royal Navy's own immediate research needs, the EMU's wide range of new facilities could well produce medical research data of international interest and certainly of use to the other Armed Services, Government Departments and industry. Later, its facilities could be extended directly to other government bodies.

Exacting specifications were applied to the EMU's construction. Obviously this must be so in building an airtight installation in which fine control of climate and atmosphere content is a prime requirement. Other factors are not so obvious—such as the need to use materials, surface finishes and adhesives that would not of themselves contribute unwanted contaminants to the chamber's air. A full *dress rehearsal* for the EMU began on November 12th, when four volunteer medical ratings from the near-by Royal Naval Hospital, Haslar went into *isolation* for four weeks to help the EMU doctors, scientists and technicians check out the systems. With their medical training they were able to speed up the process of taking test samples and checking out chamber procedures. Also during this period the volunteers were to be exposed to raised carbon dioxide (CO_2) levels in the atmosphere. CO_2, exhaled during ordinary breathing, builds up in any enclosed air space,

and in a submarine, for instance, requires special machinery to remove it called CO_2 scrubbers. The levels of CO_2 for the first run will be those at which certain minor biological changes have been seen in earlier work in submarines on patrol. The changes seen may have been due to many other factors in the submarine environment, and the aim is to prove that the effects were, in fact, caused by CO_2.

First of the longer-term investigations is expected to start early in 1974. Twelve rating volunteers will then spend 75 days in the chamber while the research team accurately measure the effects of long-term exposure to CO_2 levels approximating to those found in nuclear submarines today. The objective in this case is to define the maximum acceptable level for continuous exposure of human beings to raised CO_2 so that the designers of the submarine CO_2 scrubbers have a specific design requirement for the future.

Living conditions in the 12,000 cubic-feet space will, in some respects, be at least as comfortable as the ordinary everyday level in submarines at sea. Volunteers will not be subjected to any more physical discomfort than they might expect to encounter during their normal year-round duties but they will be totally and continuously isolated in the chamber, night and day, for long periods.

Later work already being planned for the EMU includes the study of the effects of carbon monoxide, a very common atmosphere pollutant in everyday life as well as in nuclear submarines, on the body, particularly on the heart and blood circulatory system. It is thought that information of considerable interest to the medical world as a whole will be obtained in these investigations as it is already known that there is a close relationship between carbon monoxide, smoking and heart disease.

It will also be possible for other factors to be studied during the isolation experiments, and already a number of universities and other research authorities have expressed a desire to participate in the investigations in the fields of vitamin deficiency, hormone control, and applied psychology. Any proposals for parallel work from outside bodies, arising because of the unique research circumstances presented by the Unit and its facilities, will be considered provided they do not affect the main Naval objectives of the studies.

BRUNEL

J. K. M. Aked

Admiralty Surface Weapons Establishment

Brunel is a name often heard nowadays now that Uxbridge is the home of a rapidly-expanding university complex. Why Brunel, and what is the significance in the name ? The answer is that it was chosen for its association with a particularly brilliant engineer, Isambard Kingdom Brunel, who stood head and shoulders above an outstanding galaxy of engineers of his era.

Born on the 9th April 1806 at Portsea, the only son of Marc Isambard Brunel (who developed the block-making machines for manufacturing the vast numbers of these components required for sailing ships); I.K.B. (as we shall refer to him) displayed his genius early in life. At the age of four years he was drawing quite well, by six years he had mastered Euclid. Sent to Dr. Marell's boarding house at Hove, the boy amused himself in his spare time by making a complete survey of the town and sketching all the important buildings. By such means he developed extraordinary powers of observation.

As a young boy he was sent to the College of Caen in Normandy, and at 14 to the Lycée Henri Quatre of Paris, famous for mathematical tuition. His Continental education was completed by a short apprenticeship under Louis Breguet, the greatest watchmaker the world has ever known, and this training taught him the value of precision engineering.

By 1822 he returned to England to work in his father's office at 29 Poultry, Cheapside, London. He spent a lot of time with Maudslay, Son and Field of Lambeth gaining experience with heavy engineering. By 18 years of age he knew as much about engineering as professional engineers many years his senior, and was assisting his father in the boring of a tunnel under the Thames. The father had invented the shield method of tunnelling together with a new way of sinking vertical shafts, a method claimed as new in a television programme some time ago, by building the brick shaft cylinder and then excavating beneath the base in order to allow the cylinder to sink under controlled conditions.

At 23 years of age he undertook his first major project when he designed the Clifton Suspension Bridge, which design was accepted in preference to the ugly conventional bridge submitted by Telford — another notable engineer. Telford's design required a centre pier rising from the river bed—an ungainly design which won the bridge design competition but was later rejected in a second competition caused by Brunel's vigorous defence of his own design. Many difficulties, mainly financial, had to be surmounted before the completion of the bridge, but it stands today, powerfully astride the river Avon, a monument to the genius of Brunel.

In 1833, now at the ripe old age of 27, I.K.B. was appointed engineer of the Great Western Railway. He developed his broad-gauge railway links westward until he met the sea, meeting and overcoming immense problems on the way. Dividing Cornwall and Devon, the river Tamar forms a formidable natural barrier almost isolating Cornwall from the mainland. I.K.B. rose admirably to the challenge and, in spite of all the jeremiahs' warnings, he built his famous Saltash Bridge, still standing proudly today as a splendid example of the aesthetic appeal of a fine engineering design. It was the last of his major railway projects, a magnificent farewell to a phase of bridge-building combining artistry with function.

The Royal Albert Bridge crossing the Thames at Maidenhead was built under onerous conditions imposed by the Thames Commissioners. I.K.B. solved the problems brilliantly and crossed the Thames with the largest and flattest brick arches ever built. With one pier in the centre of the river, each arch has a span of 128 feet with a rise of only 24 feet at the crown. The bridge was confidently expected to crash into the Thames when the timber supports were removed, and crowds assembled to witness the splash. Confounding the critics, the bridge still stands today.

Not content to build routes only, I.K.B. designed his own locomotives. *Great Western,* built to his design, was given her first run with the Exeter express; taking 208 minutes and 211 minutes respectively for the down and up journeys, she produced an average speed of 55 miles per hour. It was a magnificent achievement for the time — 1st June 1846. By the 13th June a train of 100 tons was hauled from Paddington to Swindon non-stop at an average speed of 59 miles per hour. From Swindon's locomotive shops rolled out an impressive array of 8 ft. singles, *Iron Duke, Great Britain, Lightning, Emperor, Pasha* and *Sultan.* But I.K.B's superior broad gauge was eventually ousted by the narrow gauge, a retrogressive step as judged by modern engineering knowledge.

I.K.B. brought his enormous engineering skill to bear on the design of a steam-driven ship to cross the Atlantic, an impossible feat according to the experts because it was thought that such a ship could not carry enough coal to sustain such a distance. With I.K.B's superior technical and mathematical powers the problem was resolved. I.K.B. realised that whereas the carrying capacity of a ship increases with the cube of its dimensions, the resistance to its motion increases only as the square, *i.e.* larger ships require proportionally less power per ton to drive them through the water. Putting this principle into practice, *Great Britain,* built in 1846 to I.K.B's design,

was the first screw steamer to cross the Atlantic. Following up this triumph, he designed *Great Eastern*—far bigger than any other ship of her time or for many years thereafter—but he did not live to see her completion. She was launched in 1859 a few days before his death, brought on by severe overwork and the individual responsibility borne by him, for this was an era when engineers were not only responsible for the overall design but also attended to each of the petty details of design as well, as they arose. In this sphere Brunel excelled, and his lack of delegation to subordinates drove him to his death.

Brunel was at once an architect, naval architect, civil and mechanical engineer, at home in any branch of engineering or scientific knowledge of the time. At 24 he was elected a Fellow of the Royal Society for his major contributions to " Natural Knowledge " an honour usually accorded only to those of riper years.

An article of this length can only touch upon the outline of Brunel's achievements. Many other facets have not been touched upon; for example, he originated the polygonal rifling used in small and large guns, devised new methods of engineering production, and introduced new materials into engineering use. On the 15th September, 1859, at the age of 59 Brunel died, a victim of his own prodigous mental and physical efforts. He never asked his men to undertake any task he was unwilling to do himself, and his courage in the face of physical danger would have earned a Victoria Cross on the battlefield. So next time you pass Brunel University; or stand in Paddington station and look at the vast covered area designed by Brunel, the largest in the world when built; or view one of the bridges mentioned here, or travel by rail westward along the old routes wrested from land unchanged for thousands of years; spare a moment to consider how the brilliance of one man accomplished all this and more in the short space of 35 years.

NOTES AND NEWS

Admiralty Surface Weapons Establishment

The last few weeks has seen the retirement of three of the establishment's oldest inhabitants, all of whom joined just before the second world war. The first was **Mr. H. C. Gerry,** PSO, who during the course of his career worked on Infra-Red Detection and Direction Finding, Radar, VHF and UHF Communications, and Submarine Communications which have taken up the last decade of his professional life. The second is **Mr. L. J. (Les) Harley,** SSO, whose career included many years on the measurements of the Navy's first radar equipments and their components in the fields at Funtington, the ship-fitting of an anti-surface-vessel radar in merchant ships, and microwave measurements and system engineering work in support of the guided missile radar system for *Seaslug.* **Mr. V. P. B. (Vic) Murrell,** SSO, joined DEE in Whitehall before getting called up in the RNVR on the outbreak of war and his career has included work on the design of RF transmitters, Shock and Vibration studies, Displays, and Rolling Platforms.

Mr. K. G. Hambleton, SSO, has joined the establishment from the Services Electronics Research Laboratory at Baldock and is now working in the Guns and Guided Weapons Systems Division.

D. L. H. Blomfield's paper on " The Short-Term Frequency Stability of an L-Band Oscillator with a Superconducting Cavity" written in collaboration with A. J. Pointon of Portsmouth Polytechnic was published in Electronics Letters on 20th September (Vol. **9** No. 19).

A number of members of the establishment's staff have recently travelled abroad in connection with their work. Dr. D. O. Cummins, SSO, attended the NATO Defence Research Group Laser Seminar held at Ottawa, 26th - 28th September 1973. Mr. H. E. Walker, PSO, recently visited the United States to attend the EMP Symposium held at the Kirtland Air Force Base. Mr. W. E. Lauder recently attended the sea trials off Heligoland of some new communications equipment developed by the Federal German Navy. Mr. R. H. Stretton, PSO, of the Admiralty Compass Observatory, recently spent a few days at Gibraltar rendering technical assistance to H.M. Submarine *Swiftsure's* SINS installation. Mr. D. R. Jarman has recently visited both Paris and Wageningen in the Netherlands in connection with the work of the Anglo-French Working Party of the Channel Navigation Information Service.

**Admiralty Compass Observatory—
Navigation Division of ASWE**

During September Mr. P. A. C. Kennedy delivered a paper on " Integrated Navigation " at a meeting of the Nautical Institute in Plymouth. In November Mr. Kennedy attended the meetings of two NATO Special Working Groups. He was a member of the MCM meeting at Kiel and was Chairman of the Integrated Navigation meeting at the Hague.

Mr. J. C. Marshall and Fl. Lt. Jenner, RAF recently spent a week in Hong Kong carrying out magnetic surveys of the Kai Tak Air Force Base.

Mr. A. G. Patterson led the British delegation attending the Sixth Anglo-American Gas Bearing Conference at Northwest University, Chicargo and was joint Chairman. Mr. A. S. Huxley presented a paper on the " Optical Measurement of Running Clearances in Spiral Groove Thrust Bearings ". The delegates subsequently visited American gyro firms and laboratories. Mr. Patterson also presented a paper at Bristol University, before the Society of the Chemical Industry, on " Friction, wear and boundary lubrication in self-acting gas bearings ".

Messrs. A. P. Reilly, R. A. Leonards, J. A. Drelick of the US Navy Department visited the ACO under the terms of the Information Exchange Programme on Inertial Navigation.

Captain J. M. H. Cox, RN and the Royal Navy Presentation Team twice delivered their excellent " Why Navy ? " presentation to packed audiences at the ACO in December.

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Admiralty Engineering Laboratory

On the 11th October some 30 members of the Diesel Engine Users Association were taken on a conducted tour of the engine test and engine component evaluation facilities at AEL. The interest shown was emphasised by an early request for another such visit to he arranged.

Early in November the establishment was visited by Mr. B. W. Lynthall, Deputy Controller R & D Establishments and Research A who managed to meet a large number of the staff in a relatively short time.

Another welcome visitor was Mr. E. W. L. Satchell, D.D.Eng.(L), just prior to his appointment as D.Eng.(Ships).

On the 11th December Mr. D. N. Harvey presented a paper entitled " Diesel Engine Coolant Investigations " at the Institute of Marine Engineers.

Mr. R. H. Satchell presented his paper on " Shock Testing for the Naval Environment " at the Marine Environment Symposium held at Imperial College on 12th December by the Society of Environmental Engineers.

Messrs. D. H. Collins and A. E. Lees recently represented AEL at a Colloquium on Electrolytes for Power Sources.

On the 21 December Mr. A. D. Alexander, SSO of the Electronics and Nucleonics section said farewell to his many colleagues at AEL as early in the New Year he transfers to DUWP(N) at AUWE as a Programme Officer. He will be remembered for his successful efforts in developing electronic governors from their infancy to the stage where they are now in production.

Central Dockyard Laboratory

George James Edwin Lock retired on 28th September 1973, after 44 years of Government Service. He joined Mine Design Division, H.M.S. *Vernon* straight from school as a laboratory boy in 1929 and was appointed laboratory assistant in 1936.

In 1943, he moved to UCWE and made a name for himself by developing an uncanny knack in the use of soluble plugs, selecting the right material in the right quantity to achieve the life required. On the closure of that establishment in 1959, he moved to the Exposure Trials Station of the Central Dockyard Laboratory, where he worked on the practical evaluation of materials, particularly paints; finally contributing to the programme of biological research.

He will be remembered for the laboratory skills he displayed in the art of glass blowing, brazing and the construction of apparatus. It was these skills which made him such an important member of the various teams in which he served, and ranged from the construction of a long high temperature furnace from an old gun barrel to complex perspex tanks for biological experimentation.

George has always been a conscientious and loyal member of the staff and he will he missed much by his colleagues. Significantly contributors to his retirement present are serving in four different establishments, which says much for the regard in which he is held by erstwhile colleagues, as well as those in daily contact with him.

He was dined out by his friends and presented with a carriage clock to mark the occasion.

BOOKS RECEIVED FOR REVIEW

Offers to review should be addressed to the Editor

Ocean Engineering Wave Mechanics
Michael E. McCormick. John Wiley & Sons, 1972, £6·25 (No. 1870).

Marine Physics
R. E. Craig. Academic Press, 1973, £1·90 (No. 1860).

Dynamic Response of Structures
George Herrman and Nicholas Perrone. Pergamon Press, 1971, £9·50 (No. 1849).

An Engineering Approach to Linear Algebra
W. W. Sawyer. Cambridge University Press, 1972, £4·00 (No. 1847).

Numerical Ranges of Operators on Normed Spaces and of Elements of Normed Algebras
F. F. Bonsall and J. Duncan. Cambridge University Press, 1971, £1·40 (No. 1811).

Machine-Tool Dynamics. An Introduction
D. B. Welbourn and J. D. Smith. Cambridge University Press, 1970, £2·00 (No. 1779).

Calculations in Physical Chemistry
B. W. V. Hawes and N. H. Davies. The English Universities Press, 1972, £1·65 (No. 1842).

Solving Problems in Physics, Dynamics, Electricity and Magnetism
E. W Laing and W. McFarlane. Oliver & Boyd, 1972, £1·75 (No. 1841).

General Cohomology Theory and K-Theory
Peter Hilton. Cambridge University Press, 1971, £1·40 (No. 1810).

Certificate Mathematics
N. Abott. The English Universities Press Ltd., 1972, £1·25 (No. 1838).

Introduction to System Safety Engineering
William P. Rodgers. John Wiley & Sons Ltd., 1972, £4·75 (No. 1835).

Linear Differential Transformation of the Second Order
F. M. Arscott. The English Universities Press Ltd., 1971, £5·45 (No. 1828).

Convex Polytopes and the Upper Bound Conjecture
P. McMullen and G. C. Shephard. Cambridge University Press, 1971, £2·00 (No. 1817).

NOTICE TO READERS

The Editor extends to all readers of the Journal and particularly those of the younger generation, a cordial invitation to contribute articles of R.N.S.S., naval or general scientific and technical interest.

Authors are requested particularly to note that as the Journal is in the Restricted category the printing of material within its pages does not constitute open publication and does not prejudice the subsequent use of the material in the Journal of a learned society or institution, or in the scientific and technical press.

Manuscript should be typewritten if possible, in double spacing and on one side of the paper only. It should include, in addition to the title, the name of the Author together with initials, degrees and department, establishment or ship. Pseudonyms are acceptable only in special circumstances. A convenient length is between 3,000 and 5,000 words, but other lengths are acceptable and no contribution would be debarred on this ground alone. Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making. A recent photograph and biographical note of the Author(s) will also be welcomed.

Views and opinions expressed in the Journal are not necessarily endorsed either by the R.N.S.S. or by the Editor.

All communications should be addressed to:—

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